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SURVEY OF COAL AVAILABILITIES BY SULFUR CONTENT

A REPORT BY THE MITRE CORPORATION
TO THE ENVIRONMENTAL PROTECTION AGENCY,
OFFICE OF RESEARCH AND MONITORING,
NATIONAL ENVIRONMENTAL RESEARCH CENTER,
RESEARCH TRIANGLE PARK, NORTH CAROLINA

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SURVEY OF COAL AVAILABILITIES BY SULFUR CONTENT

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FINAL REPORT

by

THE MITRE CORPORATION

FOR THE ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND MONITORING
NATIONAL ENVIRONMENTAL RESEARCH CENTER
CONTROL SYSTEMS DIVISION
RESEARCH TRIANGLE PARK, NORTH CAROLINA

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THE
MITRE
CORPORATION
WASHINGTON OPERATIONS

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ABSTRACT

This report quantifies present and possible future availabilities of coal by rank and sulfur content. Coal reserves, coal production and mining growth potentials are presented. The potentials of physical cleaning and the potentials of Rocky Mountain Strippable reserves to provide low-sulfur coal for central and eastern markets are also examined.

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GLOSSARY

Depletion	the tonnage mined plus the coal lost as a result of the mining operation.
High Sulfur Coal	refers to coal containing over 2 percent sulfur, by weight.
Known Marginal and Submarginal Resources	deposits whose location and general magnitude are established and are not now commercially attractive.
Known Recoverable Reserves	deposits whose location and general magnitude are established and that are recoverable at, or close to present prices.
Low Sulfur Coal	refers to coal containing less than 1 percent sulfur by weight on an as received basis.
Medium Sulfur Coal	refers to coal containing 1 to 2 percent sulfur, by weight on an as received basis.
Recovery Factor	that proportion of the resource that is technically capable of being produced, usually expressed as a percent.
Remaining Reserve	the total original coal reserve reduced by depletion computed from past mining production.
Stripping Ratio	the ratio of overburden to coal, expressed generally in two ways: 1. As cubic yards of overburden per ton of coal either mined or marketable. 2. As average section of overburden thickness per foot of coalbed thickness.

Strippable Reserve (s)	the strippable resource adjusted to conform to the current economic conditions, and further reduced by the amount of coal that for various other reasons cannot be mined.
Strippable Resource	the total quantity of coal in place under a specified maximum depth of overburden and mineable by surface methods.
Undiscovered Recoverable Resources	suspected deposits whose presence and character are indicated by geological evidence.

1.0 INTRODUCTION

1.1 Objective

- Quantify the current and future potential availability of coal by sulfur content.

1.2 Background

The demand for coal to fire steam generating facilities is steadily growing. The additional annual BTU demand from coal to fire new coal-fired electric generating capacity put on-line during the period 1971-1976 is estimated to be of the order of 700×10^{12} BTU annually (i.e., equivalent to 30×10^{6} tons of bituminous coal with an average heat content of 24×10^{6} BTU/ton). More than 80% of this demand is required to fuel new utility capacity.

The required BTU value for firing coal-fired steam electric plants has in the past and undoubtedly will in the future be supplied by coals of various ranks. Coals are classified, in accordance with the American Society for Testing Materials Standards (D388-66), by rank from lignite to anthracite. Classification is based on "mineral matter free" amounts of fixed carbon, volatile matter, and BTU value. This classification system is provided by Appendix I.

1.3 Approach

This study quantifies present and possible future availabilities of coal by rank and sulfur content. In this regard, coal reserves, steam coal production, and mining growth potentials are quantified. In addition the changes in eastern coal availability by sulfur content that would result from physical desulfurization are also quantified.

This effort also investigates the suitability of Rocky Mountain production potential by coal rank and sulfur content to satisfy eastern market growth demands. This includes considerations of mining growth amenabilities and associated transportation considerations.

1.4 Description and Content

The detailed results of this task are presented in this document. This document is organized as follows:

Section 2.0 - Summary
Section 3.0 - Conclusions
Section 4.0 - Coal Reserves
Section 5.0 - Coal Production
Section 6.0 - Rocky Mountain Coal Supply Potential
Section 7.0 - Coal Production Growth Potential
Section 8.0 - Physical Coal Desulfurization

2.0 SUMMARY

This study examines the present and potential availability of commercial steam coal in terms of coal rank and sulfur content. Included are data on present and possible coal production growth rates in terms of coal source region, coal rank, sulfur content, present production levels, and considerations associated with new mining activities. Data contained in this report are summarized as follows:

1. A provisional estimate of United States coal resources is given in Table I below. The provided BTU values are based on weighted values of coal in place by rank and differs from the national average of coal currently burned.

TABLE I

PROVISIONAL ESTIMATES OF COAL RESOURCES OF THE UNITED STATES(1)

Category	Amount
Known recoverable reserves	198×10^9 tons (4.2×10^{18} BTU)
Undiscovered recoverable reserves	150×10^9 tons (3.2×10^{18} BTU)
Known marginal and submarginal resources	1380×10^9 tons (29×10^{18} BTU)
Undiscovered marginal and submarginal resources	1500×10^9 tons (31×10^{18} BTU)
Total	3228×10^9 tons (67.4×10^{18} BTU)

2. The distribution of known recoverable reserves by major region or basin is given in Table II below.

TABLE II

DISTRIBUTION OF KNOWN RECOVERABLE RESERVES(1,2)

Region or Basin	Known Recoverable Reserves (10^9 tons)
Northern Appalachian	15
Southern Appalachian	12
Eastern Interior	62
Western Interior	11
Northern Rocky Mountains	80
Southern Rocky Mountains	17
West Coast	1
Total	198

3. The estimated distribution of known recoverable according to coal rank and sulfur content is as follows in Table III.

TABLE III

ESTIMATED RANK AND SULFUR CONTENT* DISTRIBUTION OF KNOWN RESERVES(2)

	Part of Total	S 1%	S 1-2%	S 2%
Bituminous	46%	13.7%	6.2%	26.2%
Subbituminous	24.7%	24.6%	0.1%	-----
Lignite	28.4%	25.8%	2.6%	-----
Anthracite	0.9%	0.9%	----	-----

(* on a dry basis)

4. The total estimated recoverable reserves in million of tons (bituminous, subbituminous, and lignite) by sulfur contents up to a maximum 2% sulfur by weight are provided in Table IV.

TABLE IV

LOW AND MEDIUM SULFUR RECOVERABLE RESERVES[2] (Jan. 1965)

(million tons)

Sulfur Content % Wt. (dry)	0.7	0.8-1.0	1.0-1.5	1.5-2.0
Bituminous and Subbituminous	28,650	25,445	7,530	6,805
Lignite	37,905	6,750	4,530	0

5. More than half of the potential coal reserves of the United States lie in a belt approximately 500 miles wide which straddles the Rocky Mountains and runs from Canada to Mexico. The quality of these coals varies both in carbon content and volatile matter. The magnitude of these reserves is such that, with an assumed recovery rate of 50 percent and a national consumption rate of 600 million tons per year, they could satisfy the needs of the United States for hundreds of years. Estimates of coal reserves of Rocky Mountain states (as of Jan. 1965) by rank are given in Table V.

TABLE V

COAL RESERVES OF ROCKY MOUNTAIN STATES[2,3] (Jan. 1965)

(million tons)

	Bituminous	Sub-Bituminous	Lignite	Anthracite	Total
Arizona	--	4,000	--	--	4,000
Colorado	62,416	18,300	--	90	80,806
Montana	2,105	132,117	87,482	--	221,704
New Mexico	10,686	50,735	--	6	61,427
Utah	27,658	150	--	--	27,808
Wyoming	12,820	107,904	--	--	120,724
North Dakota	--	--	350,698	--	350,698
South Dakota	--	--	2,031	--	2,031
TOTAL	115,685	309,206	440,211	96	865,198

6. In order to estimate the western coal reserves in each sulfur category, it was necessary to build a data base of coal analyses. Rocky Mountain region coal characteristic statistics obtained from our data base are given in Table VI.

TABLE VI

ROCKY MOUNTAIN REGION COAL CHARACTERISTICS

		Avg. Value	Std Dev.	No. of Analyses
I.	Bituminous Coal			
	Moisture Content (wt.%)	7.7	3.49	1210
	Volatile Matter (wt.% dry)	40.3	4.24	949
	Fixed Carbon (wt.% dry)	51.4	3.78	949
	Ash (wt. % dry)	8.0	4.33	1210
	Total Sulfur (wt.% dry)	0.92	0.96	1210
	Pyritic Sulfur (wt. % dry)	0.29	0.53	261
	Organic Sulfur (wt.% dry)	0.60	0.43	261
	Grindability Index	50	8.6	107
	BTU/lb. (as received)	11,879	956.1	949
II.	Subbituminous Coal			
	Moisture Content (wt.%)	19.6	5.79	527
	Volatile Matter (wt.% dry)	40.0	3.72	359
	Fixed Carbon (wt.% dry)	51.0	4.82	359
	Ash (wt.% dry)	8.4	5.20	526
	Total Sulfur (wt.% dry)	0.80	0.71	527
	Pyritic Sulfur (wt.% dry)	0.22	0.30	168
	Organic Sulfur (wt.% dry)	0.53	0.53	168
	Grindability Index	51	9.2	30
	BTU/lb. (as received)	9,235	939.2	359
III.	Lignite			
	Moisture Content (wt.%)	36.8	4.72	221
	Volatile Matter (wt.% dry)	42.7	3.78	193
	Fixed Carbon (wt.% dry)	46.5	5.02	193
	Ash (wt.% dry)	10.5	3.61	221
	Total Sulfur (wt.% dry)	0.96	0.58	221
	Pyritic Sulfur (wt.% dry)	0.15	0.26	28
	Organic Sulfur (wt.% dry)	0.58	0.35	28
	Grindability Index	48	10.2	43
	BTU/lb. (as received)	6,763	522.9	193

Total sulfur content statistics by state from the data base are shown in Table VII.

TABLE VII

TOTAL SULFUR (DRY BASIS) STATISTICS FROM ANALYSES OF ROCKY MOUNTAIN REGION COAL SAMPLES

	Min.	Avg.	Max.	Std. Dev.	No. of Analyses
I. BITUMINOUS COAL					
Arizona	.40	.79	1.30	.31	13
Colorado	.20	.78	5.10	.55	561
Montana	.40	2.16	10.30	1.94	110
New Mexico	.40	.97	4.60	.82	89
Utah	.30	.83	6.67	1.08	231
Wyoming	.30	.71	1.60	.23	206
	.20	.92	10.30	.96	1210
II. SUBBITUMINOUS COAL					
Arizona	.40	1.32	2.30	.73	8
Colorado	.24	.49	2.42	.26	171
Montana	.30	1.19	6.10	1.02	136
New Mexico	.46	.78	1.54	.35	14
Utah	.51	1.90	6.74	1.74	12
Wyoming	.18	.70	2.70	.32	185
	.18	.80	6.74	.71	526
III. LIGNITE					
Montana	.30	.94	3.20	.67	65
North Dakota	.29	.98	2.80	.55	144
	.29	.96	3.20	.58	209

(% by wt. dry)

7. Estimates were made of annual growth in commercial steam coal production growth capabilities based on (a) the current 7% annual increase in production applied in each sulfur category, and (b) a 20 year reserve lifetime criteria. These estimates are given in Tables VIII and IX.

TABLE VIII

CURRENT ANNUAL STEAM COAL PRODUCTION GROWTH

	WEIGHT PERCENT SULFUR CONTENT (Dry Basis)	ESTIMATED ANNUAL PRODUCTION GROWTH	
		10^6 TONS	10^{12} BTU
EASTERN U. S.	<0.7	1.5	39
	<1.0	5.0	130
	<1.5	7.0	182
	All Coal	26	680

TABLE IX

ESTIMATED MAXIMUM ANNUAL STEAM COAL PRODUCTION GROWTH BASED ON RESERVES

	WEIGHT PERCENT SULFUR CONTENT (Dry Basis)	MAXIMUM ANNUAL PRODUCTION GROWTH	
		10^6 TONS	10^{12} BTU
EASTERN U. S. *	<0.7	9.4	240
	<1.0	20.4	530
	<1.5	37	960
	All Coal	165	4300
WESTERN U. S. *	<0.7	60	1250
	<1.0	110	2300
	<1.5	111	2330
	All Coal	140	2940

* Based on total known recoverable bituminous and subbituminous reserves. These include reserves not currently owned by coal producers.

8. Rocky Mountain strippable resources and reserves of coal and lignite as defined by the Bureau of Mines (Table X) are:

TABLE X

STRIPPABLE RESOURCES AND RESERVES$^{(4)}$
(millions of tons)

Rank	Remaining Strippable Resources	Strippable Reserves	Strippable Reserves		
			Low Sulfur	Medium Sulfur	High Sulfur
BITUMINOUS COAL					
Colorado	870	500	476	24	0
Utah	252	150	6	136	8
Subtotal	1,122	650	482	160	8
SUBBITUMINOUS COAL					
Arizona	400	387	387	0	0
Montana	7,813	3,400	3,176	224	0
New Mexico	3,307	2,474	2,474	0	0
Wyoming	22,028	13,971	13,377	65	529
Subtotal	33,548	20,232	19,414	289	529
LIGNITE					
	Rocky Mountain and Northern Great Plains Provinces				
Montana	7,058	3,497	2,957	540	0
North Dakota	5,239	2,075	1,678	397	0
South Dakota	399	160	160	0	0
Subtotal	12,696	5,732	4,795	937	0

Note: Bituminous coal resource and reserve not estimated for Montana, New Mexico and Wyoming.
Subbituminous coal resource and reserve not estimated for Colorado.

Some high sulfur content coal is not included in above.

9. Rocky Mountain strippable reserves of coal that are most attractive for servicing eastern markets are in the Montana-Wyoming area. These strippable coal beds, east of the Continental Divide, are located in the contiguous Fort Union region in Montana and the Powder River region in Wyoming. The less than 1% sulfur content (by dry weight) subbituminous strippable reserves (in million tons) in these two areas are "conservatively" estimated to be:

	Cumulative Values		
Sulfur Content By Wt.	≤0.5%	≤0.7%	≤1.0%
Strippable Reserves	4,000	10,700	14,700

The annual maximum production growth potential in millions of ton per year per year, based on a 20 year mining lifetime is:

Sulfur Content by Wt.	≤0.5%	≤0.7%	≤1.0%
Production Growth Potential	9.5	26	36

10. The annual production of Rocky Mountain coal is continually increasing. New mine capacities (in million tons per year) by state and year for period of 1970 through 1974 (Table XI) are:

TABLE XI

CAPACITY OF NEW MINES IN ROCKY MOUNTAIN REGION
FOR PERIOD OF 1970 THROUGH 1974 (IN MILLION TONS PER YEAR)[3]

State	1970	1971	1972	1973	1974	Total
Arizona	5.2				7.8	13.0
Montana			5.0			5.0
Utah	0.8			2.3		3.1
Wyoming	5.3	5.0	2.5		5.0	17.8
Total	11.3	5.0	7.5	2.3	12.8	38.9

11. The major possibility for increasing low-sulfur production growth potential of Eastern steam coal sources in the near term is the physical desulfurization or "deep-cleaning" of coal. The estimated potential increase in low sulfur (<1%S) bituminous steam coal production based on 3/8 in. topsize crushing and a 90% BTU yield is indicated in Table XII.

TABLE XII

ESTIMATE OF POTENTIAL INCREASE IN LOW SULFUR BITUMINOUS COAL (<1% SULFUR) VIA DEEP CLEANING
(3/8 inch top size, 90% BTU yield)

Region	Increase in Low Sulfur Steam Coal Production (in million tons)
. N. Appalachian	20
. S. Appalachian	7
. Eastern Interior (Including Ohio)	5
. Total	32
% Increase over present annual mining level of <1% eastern steam coal	56%

3.0 CONCLUSIONS

1. The current annual steam coal production growth of Eastern U.S. steam coals with sulfur contents of 0.7% or less by weight is very modest, in the neighborhood of $1.5x10^6$ tons/yr/yr.

2. The estimated maximum possible 0.7% sulfur or less by weight production growth of Eastern U.S. steam coals based on existing reserves and a 20 year production lifetime amounts to 9.4×10^6 tons/yr/yr. The growth period is of course limited by reserves in place.

3. The estimated maximum possible 0.7% sulfur or less by weight steam coal production growth of Western U.S. steam coals based on existing reserves and a 20 year production lifetime amounts to 60×10^6 tons/yr/yr.

4. The Fort Union region in Montana and the Powder River region in Wyoming have very large strippable subbituminous reserves (in excess of 10×10^9 tons) less than 0.7% sulfur content by weight. Coal from this area is attractive for eastern markets due to the quantity of reserves, the geologic features of the area, and general availability of rail lines.

5. The major cost associated with providing eastern markets with Rocky Mountain coal is the transportation cost. Therefore major cost reduction efforts should consider ways at reducing the effective transportation cost. In this regard, the total trans-

portation process must be investigated. As a rule water-borne transportation costs less than rail transportation. This advantage is somewhat reduced by the fact that some waterways do not allow a year-round capability because of freeze-ups.

An effective way of reducing transportation cost is to increase the BTU/ton content of coal prior to shipping. In general, western subbituminous coals have substantial moisture contents and a reduction in coal moisture content prior to shipping would increase the as received BTU content per ton and thereby reduce the effective transportation cost.

6. The major possibility for increasing the low-sulfur production growth potential of eastern steam coal sources in the near term is the physical desulfurization or "deep-cleaning" of coal. Statistically the maximum effect of applying the desulfurization process would be an increase in low sulfur (≤1% by wt.) steam coal production by 32 million tons annually, a 56% increase over present production at this sulfur level. The increase in production of coal with a maximum sulfur content of 0.7% (by wt.) would be 17.6 million tons annually, a 107% increase over the present annual production.

7. Cost-benefit analyses of physically cleaned coal source/user combinations indicate that economic generalizations are impractical.

Each case must be evaluated individually to determine the economics associated with physically cleaning coal. A previous study investigating 30 potential clean coal source/user combinations indicated a net cost change to the coal user ranging from a 1¢/MBTU saving to a 9¢/MBTU increase for coal physically cleaned to a 1% or less sulfur content.(5)

4.0 COAL RESERVES

When considering coal, the concept of "reserves"--usually denoting a mineral deposit of immediate or near-term economic interest--is frequently used interchangeably with the term "resources," which normally embraces reserves along with marginal, sub-marginal, and latent resources.

The known recoverable reserves of coal are those in thick coalbeds lying at depths of less than 1,000 feet. The minimum thickness of beds of bituminous and higher rank coal included in this section is 3.5 feet, and that of subbituminous and lower rank coal is 10 feet. For the purposes of this study, general coal recovery factors have been estimated as follows based on U. S. Geological Survey, Illinois State Geological Survey, and coal industry data:(6)

- underground mines - 50%
- strip mines in the Appalachian and Interior regions - 60%
- strip mines in the Rocky Mountain region - 80%

The known marginal and submarginal resources include coal left in first mining of known recoverable reserves, coal in thin beds at shallow depths, and coal lying at depths between 1,000 and 6,000 feet below the surface. The estimate assumes complete recovery of coal in place and includes coal in the measured and indicated categories of P. Averitt,(1) less that reported here in the known recoverable class, rounded to two significant figures. The undiscovered marginal and submarginal resources refer to coal believed to be in place to depths of 6,000 feet.

In the United States, coal is the only major fuel which could, by itself, meet the cumulative energy demands of the country for the remainder of the century or beyond. The resources in categories 1, 2, and 3 above are estimated in Table XIII as 1.7 trillion tons. Of this total, known coal reserves in category 1 equal about 198 billion tons. The derivation of this estimate is provided by Table XIV. The energy content of this category of reserve is 4.16 Q (quintillion) BTU.

An official sulfur content estimate of the 181 billion tons of coal in category 1 is not available, but the Bureau of Mines has prepared an estimate of the 1.6 trillion tons of total resources in categories 1 and 3.(2) This estimate of categories 1 and 3 (i.e. generally defined as "reserves") is summarized by coal rank in Table XV.

The distribution of known recoverable reserves according to seven major coal basins or comparable large regions is given in Figure 1 and Table XIV.(1) These subdivisions provide a natural breakdown of data, and they can be considered separately or combined in various ways for study and analysis. Region 1, for example, represents coal available to the densely populated, highly industrialized northeastern states. Regions 1 and 2 combined represent the Appalachian

TABLE XIII

PROVISIONAL ESTIMATES OF COAL RESOURCES OF THE UNITED STATES (1)

CATEGORY	1	2	3	4
	Known recoverable reserves	Undiscovered recoverable resources	Known marginal & submarginal resources (not economically recoverable at present	Undiscovered marginal and submarginal resources (not economically recoverable at present)
TONNAGE	198×10^9	150×10^9	1380×10^9	1500×10^9
HEAT CONTENT	4.16×10^{18} BTU	3.2×10^{18} BTU	29×10^{18} BTU	31×10^{18} BTU

(includes Alaska)

TABLE XIV

Remaining U. S. Coal Reserves - January 1967

Region or Basin	Total Known Reserves in ground of all types of coal(2)	Known Reserves in thick beds generally less than 1000 ft. below the surface** (1)		Recoverability factor(1)	Known Recoverable thick reserves	
	10^9 Tons	%	10^9 Tons	%	%	10^9 Tons
1. Northern Appalachian (Pa, No. W. Va. & Md)	115	27%	31	50%	13%	16
2. Southern Appalachian (Eastern Ky, So. W. Va., Tenn, Va & Ala)	113	21%	24	50%	11%	12
3. Eastern Interior (Ill, Ind, Western Ky. & Ohio*)	250	50%	125	50%	25%	62
4. Western Interior (Iowa, Kansas, Mo, Okla, Ark & Texas)	118	16%	19	50%	8%	10
5. Northern Rocky Mts. (N. Dakota, S. Dakota, Mont, Wyo. & Idaho)	695	22%	153	52.2%	11%	80
6. Southern Rocky Mts. (Colo. Utah, Ariz, & New Mexico)	170	20%	34	50%	10%	17
7. West Coast (Wash, Oregon, & Calif)	6	18%	1	50%	9%	1
TOTAL	1487	25%	390	50.8%	13%	198

* Ohio is included with the Eastern Interior rather than the Northern Appalachian Basin, which is normally the case, because of the higher sulfur content of Ohio's coal reserves. The importance of coal sulfur content makes this factor an important consideration in any regional grouping considered for this report.

** These reserves only include bituminous coal and anthracite in beds 42 inches or more thick, subbituminous coal and lignite in beds 10 feed or more thick, and only coal which is generally less than 1,000 feet from the surface.

TABLE XV

DISTRIBUTION OF U.S. COAL RESERVES ACCORDING TO RANK AND SULFUR CONTENT (2)*

	Low Sulfur (1% or less) % of total	Medium Sulfur (1.1-2.0%) % of Total	High Sulfur (Over 2.0%) % of Total	TOTAL % of Total
Bituminous	13.7	6.2	26.2	46.0
Sub-bituminous	24.6	0.1	-	24.7
Lignite	25.8	2.6	-	28.4
Anthracite	0.9	-	-	0.9
TOTAL	64.9	8.9	26.2	100.0

* On a "Dry" Basis

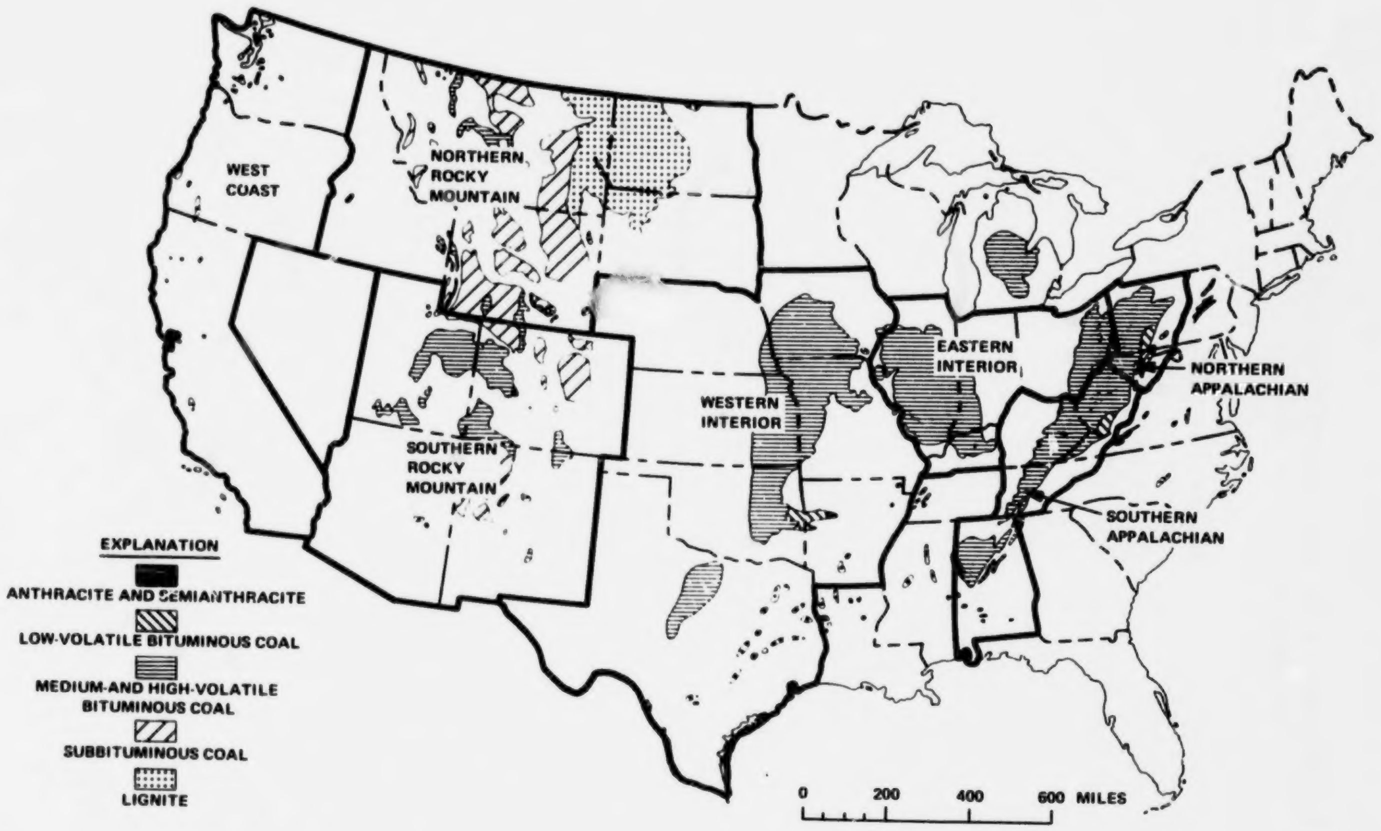

WEST COAST
NORTHERN ROCKY MOUNTAIN
SOUTHERN ROCKY MOUNTAIN
WESTERN INTERIOR
EASTERN INTERIOR
NORTHERN APPALACHIAN
SOUTHERN APPALACHIAN
EXPLANATION
ANTHRACITE AND SEMIANTHRACITE
LOW-VOLATILE BITUMINOUS COAL
MEDIUM-AND HIGH-VOLATILE BITUMINOUS COAL
SUBBITUMINOUS COAL
LIGNITE
0
200
400
600 MILES

FIGURE I
COAL PRODUCING REGIONS

coal basin, which provides coal to the eastern seaboard, and coal that is exported to Europe, Canada, and elsewhere. Regions 1, 2, 3, and 4 combined represent all coal east of the Mississippi; whereas Regions 5, 6, and 7 combined represents all coal west of the Mississippi; Regions 1, 2, 3, and 4 lie east of, and Regions 5, 6, and 7 lie west of an imaginary northeast-trending line extending from the panhandle of Texas to Minnesota, which marks an important division of regions and resources according to age and rank of coal. Regions 5 and 6 combined represent the Rocky Mountain and Northern Great Plains provinces. Region 7 represents the west coast.(1)

Table XVI summarizes the sulfur content distribution of known U.S. bituminous coal resources (categories 1 and 3) for each of the defined coal source regions. These estimates are based on Reference 2. In addition, a first order estimate of the quantity of these resources in category 1 alone is also indicated, for each sulfur content level. These values are derived from application of the fraction of total resources in category 1 as given in Table XIV. It should be noted that the sulfur categories are given on a dry weight percent basis.

The Bureau of Mines under the Environmental Protection Agency's sponsorship estimated coal availability in Appalachia. This survey of Appalachian coal producers indicated that 5.3 billion tons (1.25×10^{17} BTU) are available commercially at current prices and 7 billion (1.7×10^{17} BTU) additional tons would be available at increased costs.

TABLE XVI

UNITED STATES COAL RESERVES AND RECOVERABLE RESERVES (JAN. 1, 1965)
(IN MILLIONS OF SHORT TONS)

REGION	COAL RANK	TYPE RESOURCE	SULFUR CONTENT (BY WEIGHT) (DRY BASIS) ≤0.7	0.8-1.0	1.1-1.5	1.6-2.0	2.1-2.5	2.6-3.0	3.1-3.5	3.6-4.0	>4.0	TOTAL	% REC. RES. TO TOTAL RESERVES
NORTHERN APPALACHIAN	BIT.[1]	RES.[2]	45	2,755	21,370	23,050	27,525	11,950	8,780	7,155	800	103,430	13%
		REC. RES.[3]	5	360	2,780	2,995	3,580	1,550	1,140	930	105	13,445	
SOUTHERN APPALACHIAN	BIT.	RES.	37,275	41,025	18,135	9,890	2,770	3,510	275	45	85	113,010	11%
		REC. RES.	4,100	4,510	1,995	1,090	305	385	30	5	10	12,430	
EASTERN INTERIOR	BIT.	RES.	195	1,355	10,075	9,135	7,440	32,300	67,065	86,755	35,525	249,845	25%
		REC. RES.	50	340	2,520	2,285	1,860	8,075	16,765	21,690	8,880	62,465	
WESTERN INTERIOR	BIT.	RES.	250	770	2,475	1,180	9,170	2,070	11,340	28,975	62,685	118,915	8%
		REC. RES.	20	60	200	95	735	165	905	2,320	5,015	9,515	
NORTHERN ROCKIES	BIT.	RES.	6,275	6,815	205	395	400	175	40	25	590	14,920	11%
		REC. RES.	690	750	20	45	45	20	5	0	65	1,640	
NORTHERN ROCKIES	SUB.[4]	RES.	129,665	109,045	0	1,300	0	0	0	0	10	240,020	11%
		REC. RES.	14,265	11,995	0	145	0	0	0	0	0	26,405	
SOUTHERN ROCKIES	BIT.	RES.	38,940	56,295	0	1,525	0	0	0	0	3,995	100,755	10%
		REC. RES.	3,895	5,630	0	150	0	0	0	0	400	10,075	
SOUTHERN ROCKIES	SUB.	RES.	52,055	16,910	150	0	0	0	0	0	0	69,115	10%
		REC. RES.	5,205	1,690	15	0	0	0	0	0	0	6,910	
WEST COAST	BIT.	RES.	900	685	0	0	0	0	0	0	0	1,585	9%
		REC. RES.	80	60	0	0	0	0	0	0	0	140	
WEST COAST	SUB.	RES.	3,780	585	0	0	0	0	0	0	0	4,365	9%
		REC. RES.	340	50	0	0	0	0	0	0	0	390	
TOTAL BITUMINOUS AND SUBBITUMINOUS		RES.	269,380	236,240	52,410	46,475	47,305	50,005	87,500	122,955	103,690	1,015,960	
		REC. RES.	28,650	25,445	7,530	6,805	6,525	10,195	18,845	24,945	14,475	143,415	
TOTAL ANTHRACITE (OVER 95% IN PA.)		RES.	12,550	95	0	145	285	0	0	0	0	13,075	13% (THE N. APP. FACTOR)
		REC. RES.	1,630	10	0	20	35	0	0	0	0	1,695	
TOTAL LIGNITE (OVER 98% IN NORTHERN ROCKIES)		RES.	344,620	61,385	41,165	0	0	465	0	0	0	447,635	11% (THE N. ROCKIES FACTOR)
		REC. RES.	37,905	6,750	4,530	0	0	50	0	0	0	49,235	

[1] BITUMINOUS

[2] KNOWN RESERVES

[3] KNOWN RECOVERABLE RESERVES

[4] SUBBITUMINOUS

These estimates do not, however, take account of large deposits, both on public domain and privately held, that are not controlled by operating companies, but nevertheless could be mined under present conditions. Based on Table XVII, these additional recoverable reserves in the Northern and Southern Appalachian Regions are [illegible] excess of four times the currently marketable reserves held by surveyed (i.e., reporting) operating companies. It is interesting to note that the 12 billion tons (3 x 10^{17} BTU) under control of the independent producers represent about a 20-year supply at current rates of consumption. This is, coincidentally, considered in the coal industry as a minimum coal reserve lifetime for investing in new underground mine capacity. Such a reserve lifetime is also desired by the coal user to insure a dependable long-term supply of coal with characteristics compatible with his specific steam generator design. The Internal Revenue Service (IRS) "write-off" period for steam generator systems is 28 years.

These reserves held by operating companies in 1967 are summarized in Reference 3 as commercial, captive, and other. And further subdivided as follows:

- o assigned to operating mines;
- o scheduled new mines; and
- o reserves not assigned to either.

TABLE XVII

LOW SULFUR APPALACHIAN BITUMINOUS COAL RESERVES (MILLION TONS)

Wt. % S Content	Total Estimated Category 1 Reserves*
<0.7	4100
0.7 - 1.0	4870
1.0 - 1.5	4770

Wt. % S Content	Reserves Held By Reporting Producers and Mineable at Current Value**
<0.6	100
0.6 - 1.0	2300
1.0 - 1.5	240

* DeCarlo (2)/Averitt (1) (Table XVI)

** 1967 Appalachian Coal Data Survey

The reserves are further classified by state and county and by recovery potential at various price levels.

These 1967 Appalachian Coal Data Survey data are summarized in Figures 2 and 3 which may be compared with the Appalachian Category 1 reserves indicated in Table XVI. Of particular interest is the very limited reserve of low sulfur coal based on either (1) DeCarlo and Averitt for total Category 1 reserves or (2) the Appalachian Coal Data Survey reserves held by surveyed coal producers. Table XVII compares these two estimates.

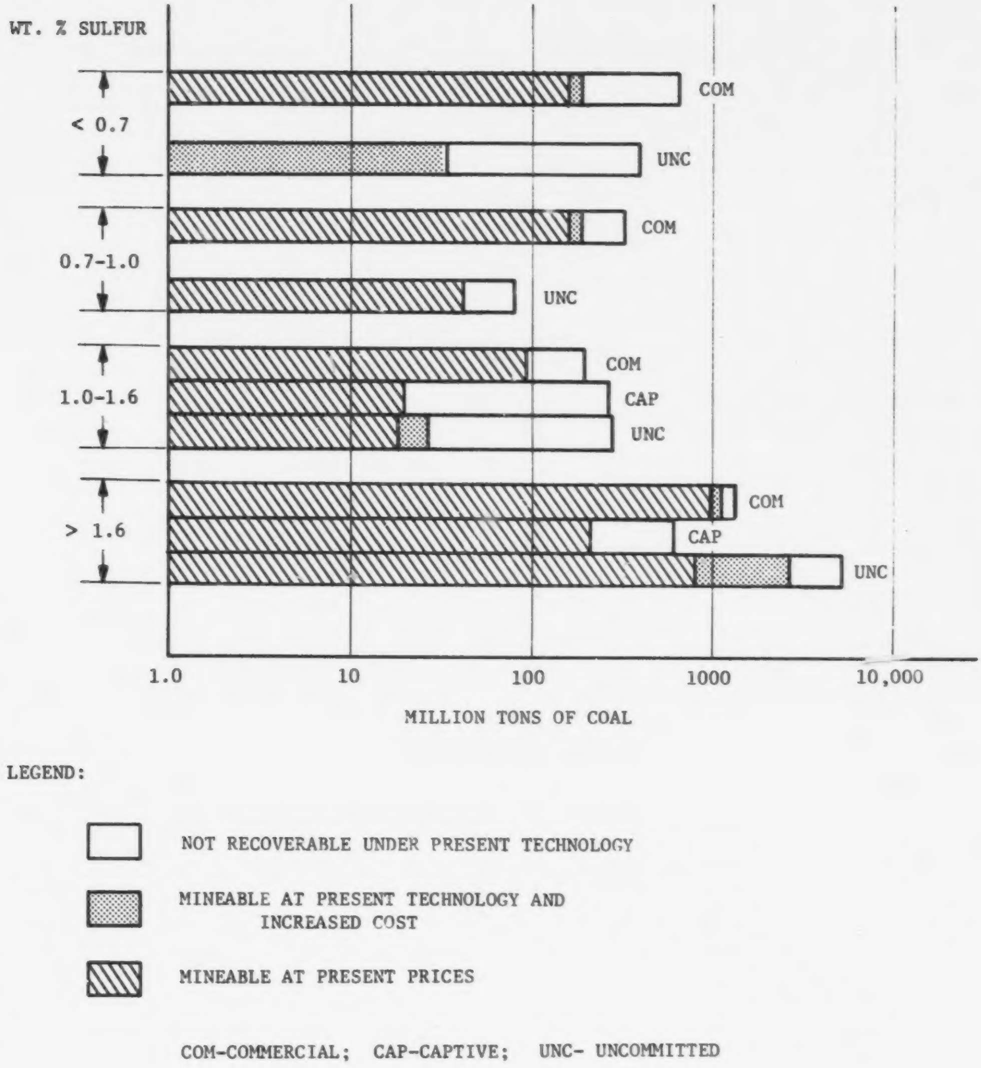


FIGURE 2
TOTAL KNOWN NORTHERN APPALACHIAN
RESERVES
HELD BY OPERATING COMPANIES
1967

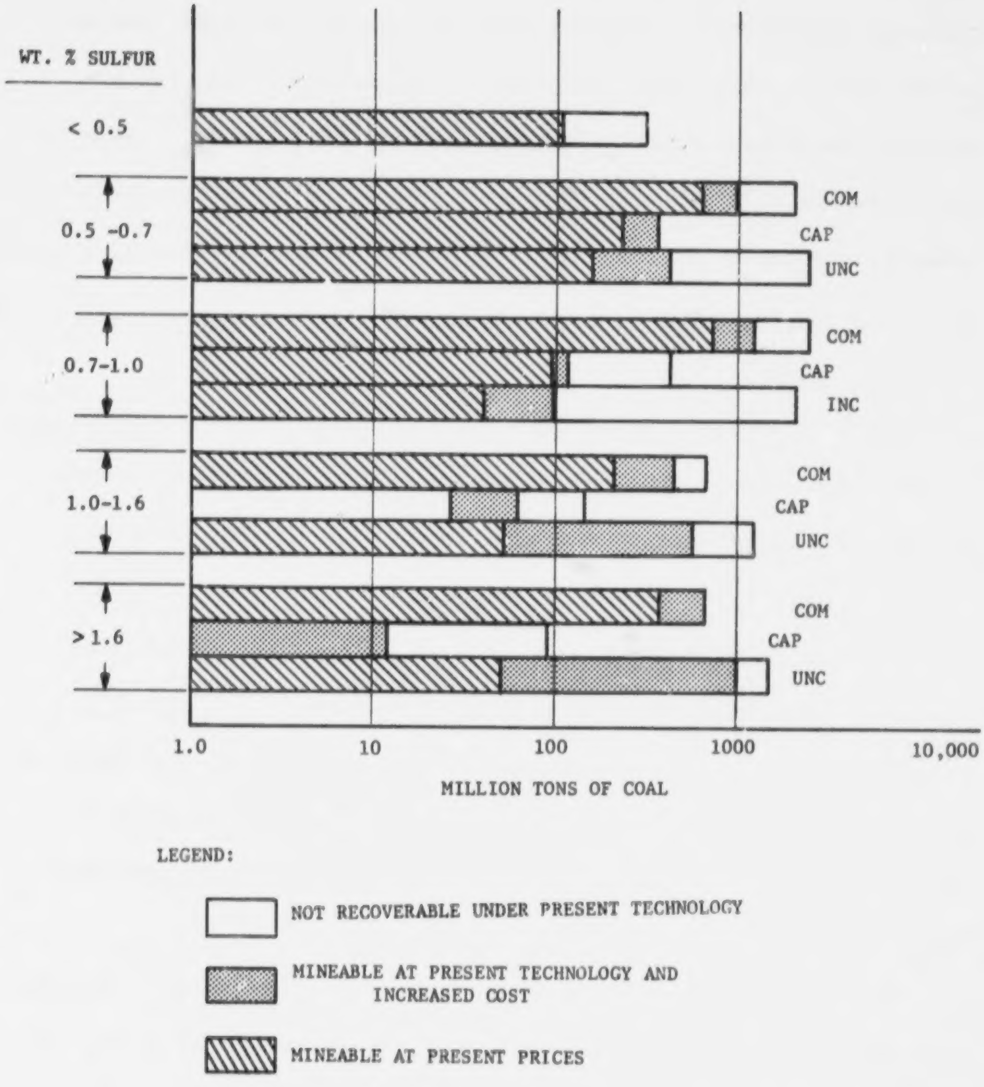


FIGURE 3

TOTAL KNOWN SOUTHERN APPALACHIAN REGION

COAL RESERVES HELD BY OPERATING COMPANIES

1967

5.0 COAL PRODUCTION

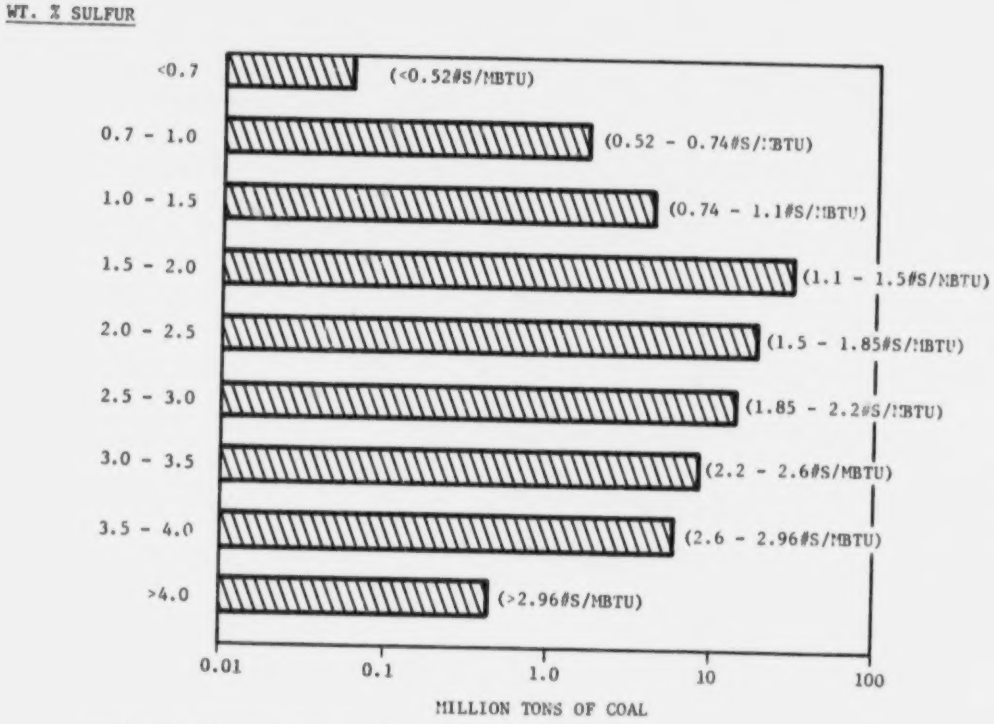
A tabulation in December 1969 of the construction of new mines and major expansion of existing mines in the United States for the period 1969 to 1973 showed that the bituminous coal industry has proposed new annual capacity averaging 35 million tons.(8) This is approximately a 7% per year growth rate based on the estimated 1970 commercial steam coal production. Over 90% of this commercial production growth will be absorbed by the electric utility steam generating industry and export markets.(9)

The sources of bituminous coal production were indicated in Figure 1 according to the three primary coal source regions having distinctive sulfur content characteristics:

- o Appalachian (Northern and Southern);
- o Interior (Eastern and Western);
- o Rocky Mountain (Northern and Southern).

The estimated 1970 coal production of each region as a function of sulfur content by weight is indicated in Figures 4 through 9 (2,7,10,11). All production is bituminous or subbituminous except where indicated to the contrary.

The relationship of current production to reserves of commercial steam coal from each of these three regions according to sulfur content is indicated in Table XVIII. Commercial is defined as all steam coal which is not held captive by various industries. This is particularly significant in the Appalachian Region where a large portion (30% of current production) is held captive by the metallurgical industry.



AVERAGE AS RECEIVED HEAT VALUE

27 X 10^6 BTU/TON

FIGURE 4
NORTHERN APPALACHIAN REGION PRODUCTION
OF BITUMINOUS COMMERCIAL STEAM COAL
(1970)

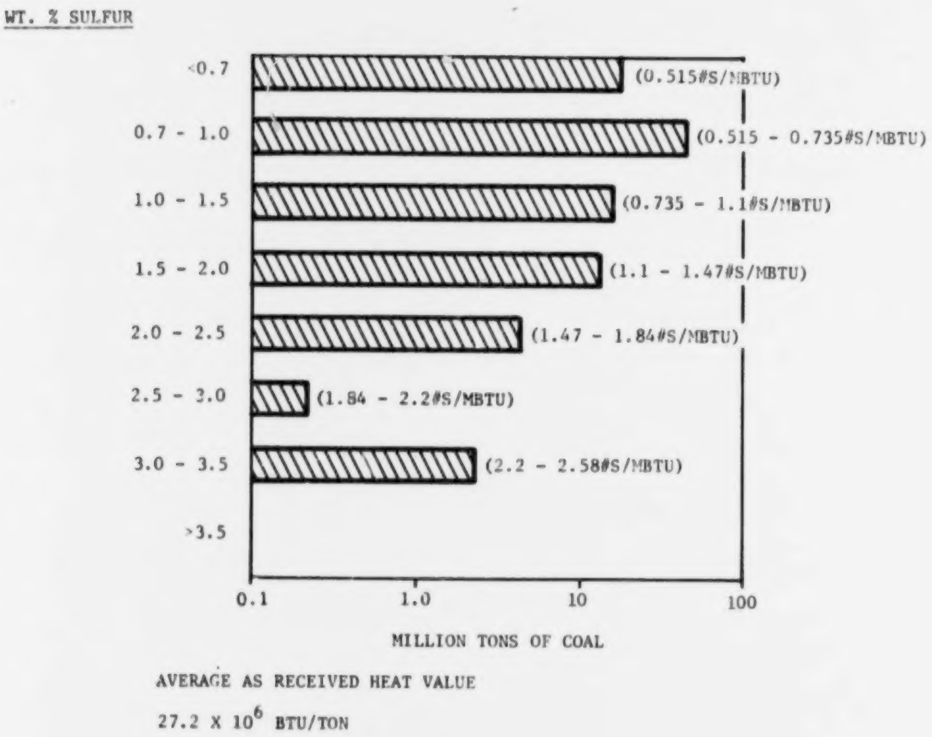
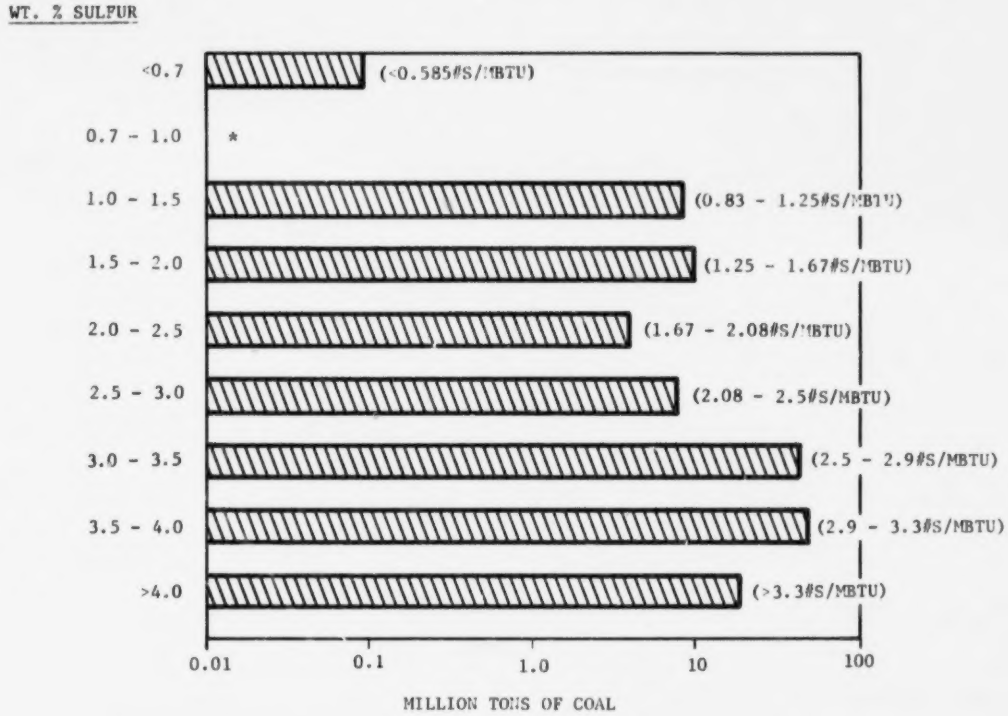


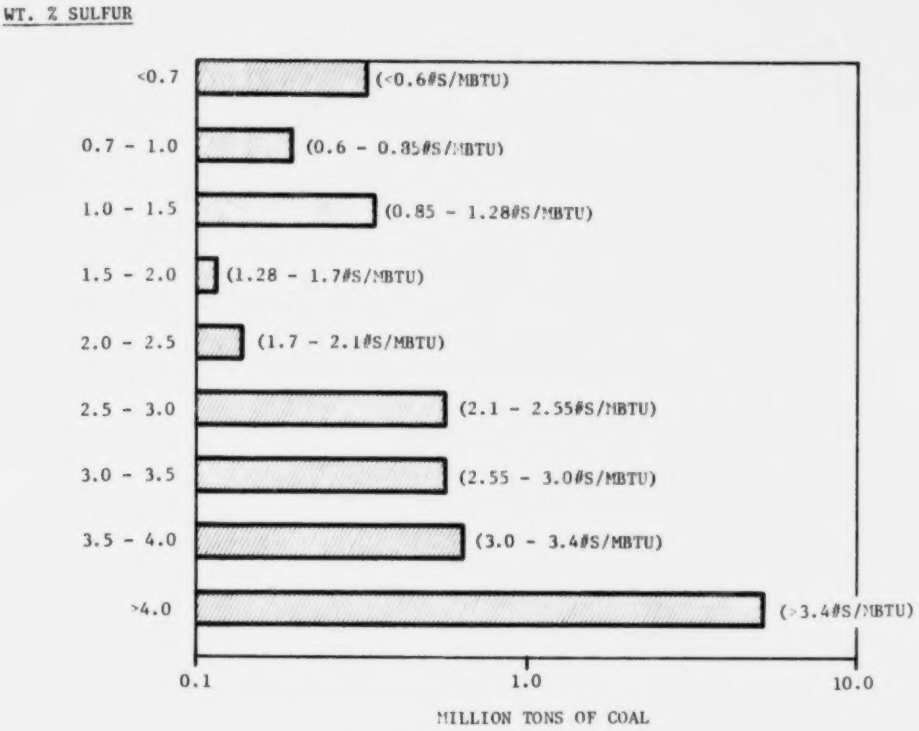
FIGURE 5
SOUTHERN APPALACHIAN REGION PRODUCTION
OF BITUMINOUS COMMERCIAL STEAM COAL
(1970)



AVERAGE AS RECEIVED HEAT VALUE
24 X 10^6 BTU/TON

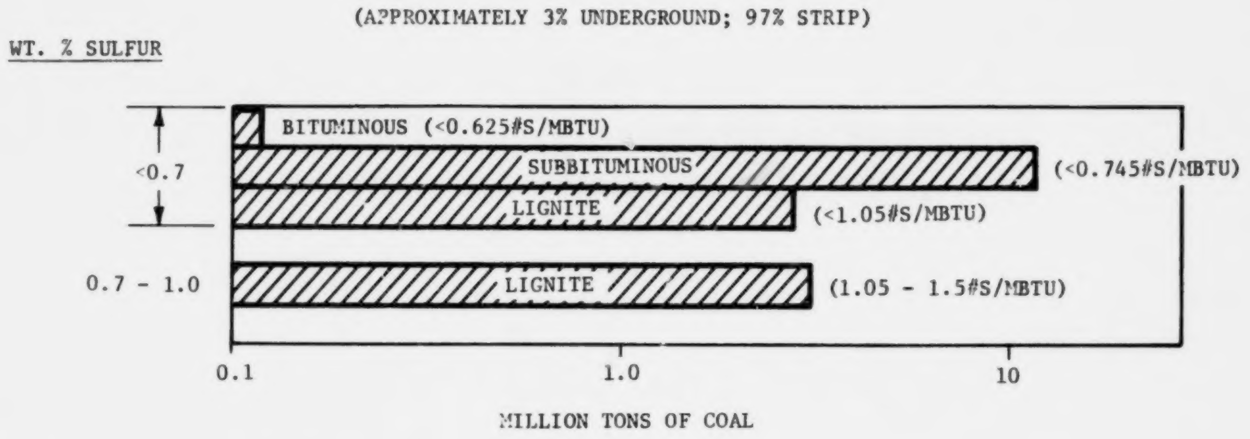
(*Included with 1.0 - 1.5% S category to avoid disclosing sensitive company data.)

FIGURE 6
EASTERN INTERIOR REGION PRODUCTION
OF BITUMINOUS COMMERCIAL STEAM COAL
(1970)



AVERAGE AS RECEIVED HEAT VALUE
23.5 X 10^6 BTU/TON

FIGURE 7
WESTERN INTERIOR REGION PRODUCTION
OF BITUMINOUS COMMERCIAL STEAM COAL
(1970)



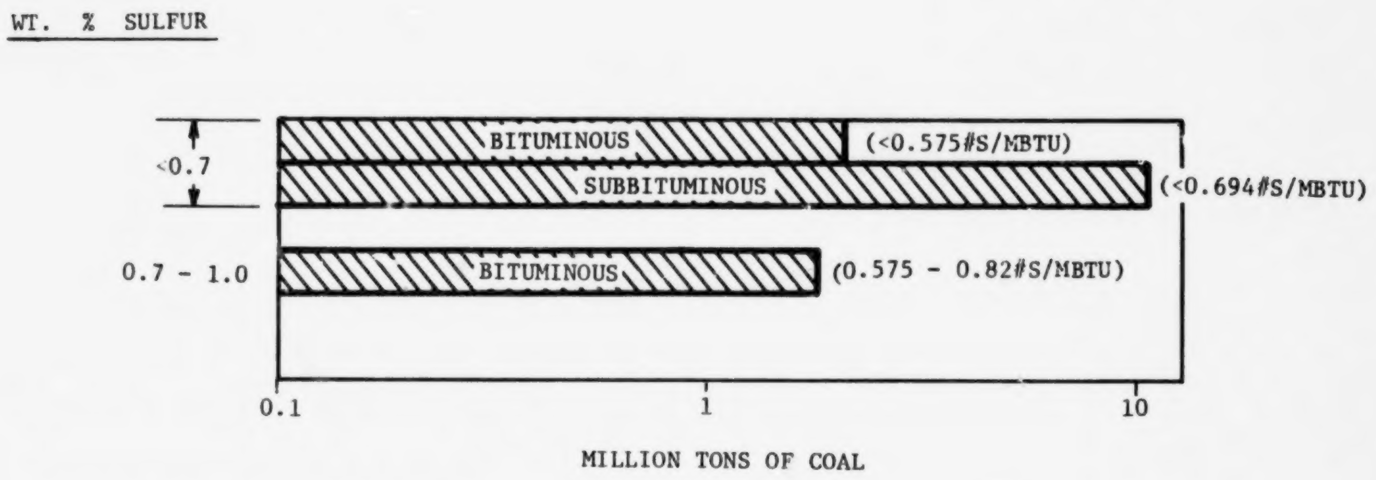
AVERAGE AS RECEIVED HEAT VALUE

BITUMINOUS - 22.4 X 10^6 BTU/TON

SUBBITUMINOUS - 18.8 X 10^6 BTU/TON

LIGNITE - 13.4 X 10^6 BTU/TON

FIGURE 8
NORTHERN ROCKY MOUNTAIN REGION PRODUCTION
OF COMMERCIAL STEAM COAL
(1970)



AVERAGE AS RECEIVED HEAT VALUE

BITUMINOUS - 24.4 X 10^6 BTU/TON

SUBBITUMINOUS - 20.2 X 10^6 BTU/TON

FIGURE 9
SOUTHERN ROCKY MOUNTAIN AND WEST COAST
REGION PRODUCTION OF COMMERCIAL STEAM COAL
(1970)

TABLE XVIII

COMMERCIAL BITUMINOUS AND SUBBITUMINOUS STEAM COAL RESERVES AND PRODUCTION

REGION	#S/10^6BTU (Dry Basis)	CUMULATIVE MINEABLE RESERVES 10^6 Tons	CUMULATIVE MINEABLE RESERVES 10^{12} BTU	ESTIMATED CUMULATIVE ANNUAL COMMERCIAL PRODUCTION (1970) 10^6 Tons	ESTIMATED CUMULATIVE ANNUAL COMMERCIAL PRODUCTION (1970) 10^{12} BTU
APPALACHIAN*	<0.6	1,650 (3,000)	43,000 (78,000)	44	1140
	<0.8	3,150 (8,000)	82,000 (208,000)	87	2260
(26 x 10^6 BTU/ton)	<1.2	4,270 (13,000)	111,000 (338,000	106	2760
	All Coal	13,400 (25,000)	349,000 (650,000)	175	4550
INTERIOR	<0.6	25	600	0.5	11
	<0.8	125	3,000	1.4	33
(24 x 10^6 BTU/ton)	<1.2	1,800	43,000	14	330
	All Coal	68,000	1,630,000	166	3980
ROCKY MOUNTAIN**	<0.6	18,000	380,000	16	340
	<0.8	31,000	650,000	24.7	518
(21 x 10^6 BTU/ton)	<1.2	43,000	900,000	24.7	518
	All Coal	45,000	945,000	24.7	518

*The cumulative mineable reserves for the Appalachian Region are estimated according to two sources. First, Reference 7, the Appalachian Coal Data Survey for producing coal companies. Second, in parentheses, total recoverable reserves based on References 1 and 2.

**Cumulative mineable reserves for the Rocky Mountain Region are limited to sources having an as received BTU content of 18 million BTU/ton or greater as indicated in References 2, 12, and 13.

The most important conclusion to be drawn from Table XVIII is that very limited commercially mineable reserves (i.e., compared to demand) of low sulfur coal, particularly at the 0.6 and 0.8 lbs. $S/10^6$ BTU level, exist within the Appalachian and Interior coal regions to support the Eastern utility industry. This industry currently consumes more than 250 million tons of coal annually.

Historically, coal for steam generation has been selected on the basis of lowest cost per million BTU. Thus, utilities in the Eastern United States have relied on low cost, higher sulfur content sources located within the Appalachian and Eastern Interior Coal Regions. This has resulted in a current average sulfur content of coal burned in utilities in the Eastern United States of about 2.1 lbs. $S/10^6$ BTU (2.7%S).

Estimates were made of the weighted average heat contents of current production steam coals. These estimates, by basin or region, are provided in Appendix II and are based on available coal analyses and production data.

6.0 ROCKY MOUNTAIN REGION COAL SUPPLY POTENTIAL

6.1 Coal Reserves

During the 15 years immediately following World War II, coal consumption in the U. S. fell steadily, while other energy sources captured increasing amounts of the growing energy market. The decline in consumption of Rocky Mountain region coal was intensified by two major factors. These were:

1. the increased availability of other fuels, and
2. the demise of the steam locomotive.

The 15-year postwar downtrend in western coal production reversed itself in 1958 and 1959. This reversal was based almost entirely on the demands of the electric power industry.

More than half of the potential coal reserves of the United States lie in a belt approximately 500 miles wide which straddles the Rocky Mountains and runs from Canada to Mexico. The quality of these coals varies both in carbon content and volatile matter. The magnitude of these reserves is such that, with an assumed recovery rate of 50 percent and a national consumption rate of 600 million tons per year, they could satisfy the needs of the United States for hundreds of years.

Table XIX shows published estimates of the coal reserves of the Rocky Mountain states by state and rank of the coal. Figure 10 shows the locations of the major coal fields of the west. These fields have not been explored sufficiently to develop more than a limited knowledge of the total reserves and, therefore, the provided figures are felt to be somewhat conservative.

TABLE XIX

COAL RESERVES OF THE ROCKY MOUNTAIN STATES(2,3)

As of January 1, 1965 in millions of tons

	Bituminous	Sub-Bituminous	Lignite	Anthracite	Total
Arizona	--	4,000	--	--	4,000
Colorado	62,416	18,300	--	90	80,806
Montana	2,105	132,117	87,482	--	221,704
New Mexico	10,686	50,735	--	6	61,427
Utah	27,658	150	--	--	27,808
Wyoming	12,820	107,904	--	--	120,724
North Dakota	--	--	350,698	--	350,698
South Dakota	--	--	2,031	--	2,031
TOTAL	115,685	309,206	440,211	96	865,198

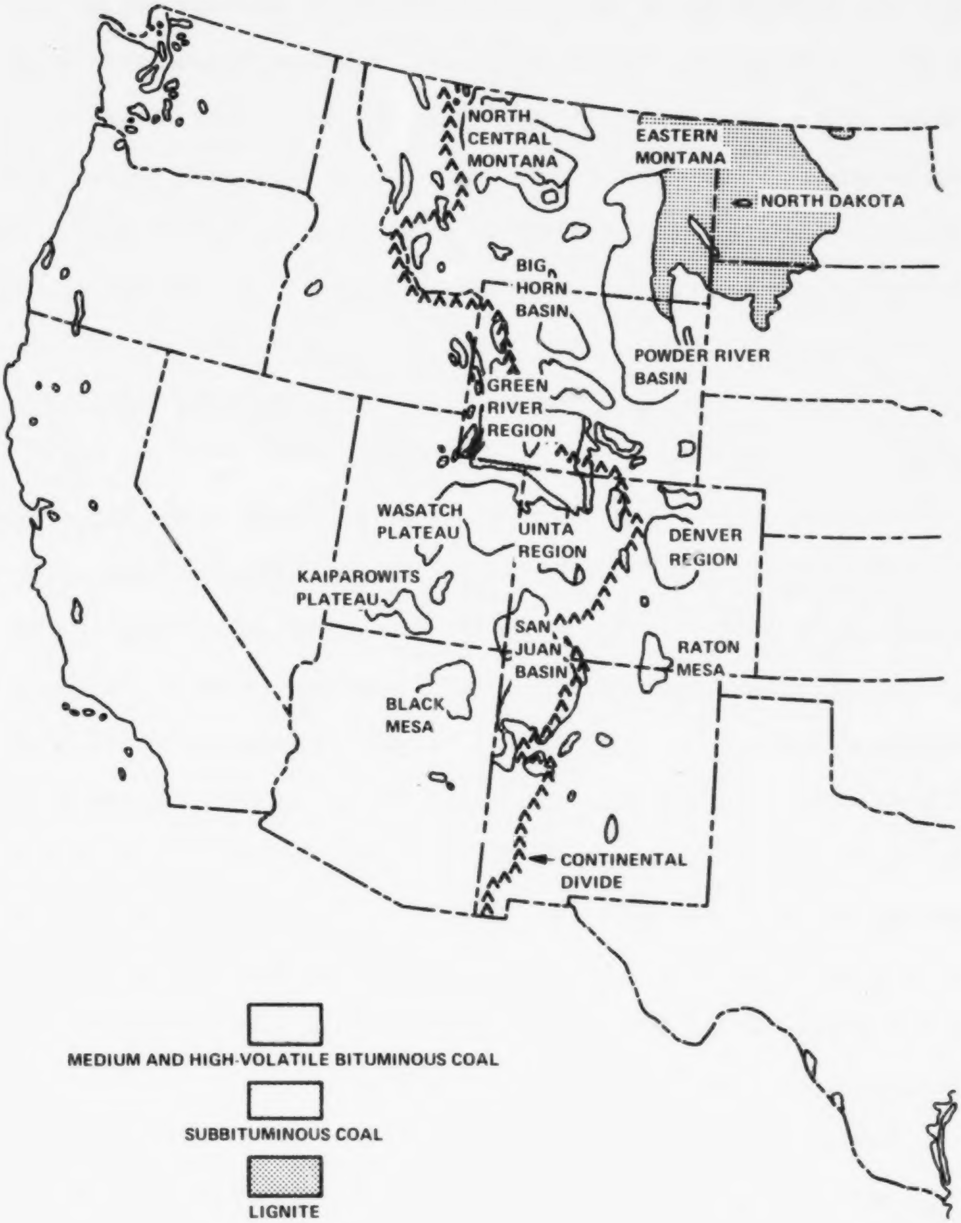

NORTH CENTRAL MONTANA
EASTERN MONTANA
NORTH DAKOTA
BIG HORN BASIN
POWDER RIVER BASIN
GREEN RIVER REGION
WASATCH PLATEAU
UINTA REGION
DENVER REGION
KAIPAROWITS PLATEAU
SAN JUAN BASIN
RATON MESA
BLACK MESA
CONTINENTAL DIVIDE
MEDIUM AND HIGH-VOLATILE BITUMINOUS COAL
SUBBITUMINOUS COAL
LIGNITE

FIGURE 10

COAL FIELDS OF THE ROCKY MOUNTAIN REGION

The feasibility of further expanding Rocky Mountain region coal production to augment Eastern steam coal supplies is basically an economic rather than a technical question. A key factor in both present cost and possible future reduction in coal cost is related to present productivity and possible increases in productivity. In this regard, mine production per man day is substantially greater for strip mining than for underground mining as indicated in Table XX. This table provides 1967 production data on average tons per man day by mine type for a number of mines in the Rocky Mountain region.(14)

Strip mining is the predominant mode of mining in the Rocky Mountain region, due both to the availability of large strippable coal reserves and to the economics of strip mining, and is the mode of mining that could most economically provide coal for eastern markets. In general, economic considerations have forced the mining industry in the Rocky Mountain region to develop very large and efficient mining operations. The larger mines are able to more efficiently utilize the variety of mining machinery available and therefore to enjoy more benefits from their use. It should be pointed out that only the large operators with definite market commitments can afford the capital cost involved in equipping and operating a large modern mine.

Due to the complexities concerning the nature of Rocky Mountain coal deposits and the associated ability of such coals to serve eastern markets, coal reserve data are provided on a state and rank basis with appropriate breakdowns in terms of county, region, seams, and formation.

TABLE XX
COAL PRODUCTION PER MAN DAY(10)

	Underground		Strip	
State	No. of Mines	Avg.Tons Per Man Day	No. of Mines	Avg. Tons Per Man Day
Colorado	55	13.3	7	66.4
Montana				
Bituminous	8	7.1	1	8.9
Lignite	1	2.2	2	76.3
New Mexico	5	21.2	3	75.3
N. Dakota (Lignite)	--	--	24	64.7
Utah	24	16.2	--	--
Wyoming	5	10.5	9	57.9

This discussion identifies factors that were considered in estimating strippable reserves and the associated coal availabilities. This discussion covers the following states: Arizona, Colorado, Montana, New Mexico, North Dakota, South Dakota, Utah, and Wyoming.

The procedure used in ascertaining the values of strippable coal resources was dependent upon the type, quantity, and quality of information that was available. The criteria for evaluating these resources were based on economic considerations for each individual area and included calculations based on outcrop, bed thickness, etc., and on estimates of the Bureau of Mines, the U. S. Geological Survey, state geological surveys, coal mining companies, and railroad companies.

Minimum coalbed thickness, maximum overburden thickness, and economic stripping ratio used in this section to estimate the strippable reserves in the various states are conservative. These values, defined by the Bureau of Mines, are summarized in Table XXI.

Table XXII indicates 1970 production by state and Table XXIII indicates percent production by stripping by state.

Overviews of per state strip mining conditions and coal resources/ reserves with gross sulfur characteristics, based on Reference 4, are as follows:

6.1.1. Arizona

Prior to 1970 there was no commercial strip coal mining in Arizona. However, the expending southwestern market for electric power and the competitive position of coal for this energy market has led to the development of strip mining in the Black Mesa coalfield in the northeast corner of the state.

TABLE XXI

Summary of Certain Criteria Used in Estimating Strippable Reserves of Coal and Lignite

Province and State	Minimum coal-bed thickness, inches	Maximum overburden thickness for computing resources, feet	Economic stripping ratio, (Feet to feet) 1/
Rocky Mountain and Northern Great Plains Provinces:			
Arizona	60	130	8:1
Colorado 3/	60	2/ 50 to 120	4:1 to 10:1
Montana	60	2/ 60 to 125	2:1 to 18:1
North Dakota 4/	60	2/ 50 to 75	3:1 to 12:1
New Mexico	60	2/ 60 and 90	8:1 to 12:1
South Dakota	60	100	12:1
Utah	60	2/ 39 to 150	3:1 to 8:1
Wyoming	60	2/ 60 to 200	1.5:1 to 10:1

1/ Based on maximum feet of overburden thickness at the highwall per foot of coalbed thickness.
2/ Maximum overburden thickness varies for different coalbeds.
3/ Additional criteria 12,000 BTU minimum and sulfur content not more than 1% by weight
4/ Additional criteria 6000 BTU minimum

TABLE XXII

PRODUCTION OF BITUMINOUS COAL, SUBBITUMINOUS COAL AND LIGNITE BY STATE FOR 1970 (11)

State	Millions of Short Tons
Arizona	0.13
Colorado	6.02
Montana	3.40
New Mexico	7.36
North Dakota	5.64
South Dakota	*
Utah	4.73
Wyoming	7.22

* No production reported

TABLE XXIII

PERCENT OF COAL MINED BY STRIPPING, BY STATE FOR 1970 (15)

State	Percent By Stripping
Arizona	100
Colorado	35
Montana	97
New Mexico	81
North Dakota	100
South Dakota	100
Utah	-0-
Wyoming	97

Competition in the market for Arizona coal is provided by extensive coal deposits in New Mexico and Utah. However, Black Mesa coal has the advantages of closer proximity to the southern California energy market, higher BTU values than New Mexico coal, and presumably lower mining cost than southern Utah coal which is expected to be mined almost exclusively by underground methods.

Commercial seams lie in the Dakota and Mesa Verde formations of Cretaceous age. Seam thicknesses average between 4 and 22 feet, and for the most part, coal seams dip approximately 2 degrees. Due to the extreme lenticularity of individual seams difficulty is encountered in seam correlation and estimation of the volume of resource. Strippable reserves (Table XXIV) of subbituminous coal, under less than 130 feet of overburden, have been estimated at 387 million tons.

6.1.2 Colorado

Strip-coal mine output in Colorado increased from insignificance through World War II up to a 1968 total of 1.8 million tons. Most of this tonnage was by three relatively large strip-mine operators in Routt County, ranking it first among Colorado's 14 coal producing counties. The only other significant strip-coal producers in Colorado are located one each in Mesa and Montrose Counties.

The most significant strip-coal production in the Rocky Mountain portion of Colorado was in the Jackson County intermountain basin of North Park. Intermittent coal production from 1909 until the latest of the abandonments in 1963 totaled about 2 million tons from the strip

TABLE XXIV

STRIPPABLE RESERVES AND RELATED CHARACTERISTICS BY STATE
(MILLION SHORT TONS)

Arizona (Subbituminous)

1. By region, formation, and county

REGION	FORMATION	COUNTY	AVG. BED THICKNESS	RECOVERABLE STRIP RESOURCE	STRIPPABLE RESERVE	SULFUR CONTENT (L, M, H)
Black Mesa	Wepco (8 seams)	Navajo	10 ft.	400	387	(L) 387

and underground mines in the Coalmont coalfield in the southwestern part of the park and from the underground mines about 20 miles eastward in the McCallum anticline coalfield.

Much of the North Park coal was used locally or by the railroads. With no such demand remaining, any future production would be handicapped by the severe winters and the lack of any feasible transportation route--except by rebuilding the 200-mile spur-railroad to Laramie, Wyoming.

Six counties of eastern Colorado (Adams, Arapahoe, Boulder, Elbert, El Paso, and Weld) in the Denver basin have production records back to 1887. Desultory small-scale mining took place some years ago in underground and strip-mined areas where the coal bed is near the surface. The coal seams are lenticular and lignitic in some places about 15 miles east of Denver. These seams extend on a southward trend through Adams, Arapahoe, and Elbert counties. The most significant underground and strip mine production (until the latest close-down in 1963) was in the subbituminous coal near the terminus of that southward trend at Franceville.

No commercial strip-coal reserves were computed for any of the Denver basin coalfields in eastern Colorado. The large reserves in the Boulder-Weld County coalfield are too deep. The large resources in Stratford, Lost Creek, and Ramah-Fondis coalfields of Adams, Arapahoe, and Elbert Counties are unavailable. The United States Air Force Academy has taken over the coal-bearing lands north of Colorado Springs, leaving only modest reserves in the Franceville coalfield.

The largest commercial stripping coal reserves in Colorado are tentatively computed for Routt, Moffat, and Montrose Counties in the Western Plateau coal province, and in North Park, Jackson County, in the Rocky Mountain province.

Due to some Colorado coalbeds, particularly in the Western Plateau province, being enveloped in hard sandstone, cutoffs used were a maximum of 50 feet of overburden or a 10 to 1 stripping ratio; a minimum of a 5-foot coalbed thickness; a minimum of 12,000 BTU per pound of coal; and a low sulfur content.

The bituminous strip-coal reserves (Table XXV) are estimated at 500 million tons.

6.1.3 Montana

Annual coal-lignite production declined from the World War II high of 4,844,000 tons in 1944 to a 1958 low of 305,000 tons. Production has since increased to about 850,000 tons in 1969, from eight underground and five strip mines in eastern Montana. Strip mines accounted for over 90 percent of the total 1969 production; over 60 percent of the production was lignite. Nearly all of the lignite and subbituminous coal production was accounted for in the Williston and Powder River Basins in the Northern Great Plains coal province.

Strippable deposits of lignite and subbituminous coal in the eastern part of Montana lie in the Tongue River member of the Tertiary Fort Union Formation. Most of the resources are in beds 20 to 30 feet in thickness; and seam thicknesses range upward to 85 feet. Deposits range in size

TABLE XXV

STRIPPABLE RESERVES AND RELATED CHARACTERISTICS BY STATE, AS OF JANUARY 1968
(MILLION SHORT TONS)

Colorado (Bituminous)

1. By region and seam

REGION OR FIELD	SEAM	AVG. BED THICKNESS	RECOVERABLE STRIP RESOURCE	STRIPPABLE RESERVE	SULFUR CONTENT (L, M, H)
North Park	Riach	30 ft.	62	4	(L) 4
North Park	Suddith	14 ft.	40	4	(L) 4
Uinta	Mesa Verde Form (8 seams)	13 ft.	216	134	(L) 134
Green River	Mesa Verde Form (6 seams)	8 ft.	330	330	(L) 330
San Juan River	No. 1	5 ft.	26	24	(M) 24
San Juan River	Low Creek	6 ft.	22	4	(L) 4
TOTALS		12 ft (avg.)	696	500	500

2. By region and county

REGION OR FIELD	COUNTY	AVG. BED THICKNESS	RECOVERABLE STRIP RESOURCE	STRIPPABLE RESERVE	SULFUR CONTENT (L, M, H)
North Park	Jackson	24 ft.	102	8	(L) 8
Uinta	Moffatt	13 ft.	216	134	(L) 134
Green River	Routt	8 ft.	330	330	(L) 330
San Juan River	Montrose	6 ft.	48	28	(L) 4 (M) 24
TOTALS		12 ft. (avg.)	696	500	500

from 10 million tons to nearly 2 billion tons; four deposits each contain more than 1 billion tons.

On the basis of pertinent literature and exploratory drilling data available from private sources and Government agencies, total available strip coal and lignite reserves (Table XXVI) for 32 deposits were estimated at 6.9 billion tons. All strippable reserves are located in the Northern Great Plains province of eastern Montana. No strip-coal reserves were computed for the scattered coalfields in the central and western parts of the state; these are generally located in terrain unsuitable for strip mining.

6.1.4 New Mexico

Strip coal mining in New Mexico has been limited to the west side of the San Juan Basin in the northwest corner of the state. The earliest (1952) strip mines were low tonnage operations in the vicinity of Gallup, where they furnished locomotive fuel to the Santa Fe Railroad. Recently, increased demand for coal by an expanding electric utility market has resulted in the opening of large strip-coal mines.

Strip mines in the southern end of the San Juan coalfield have the advantage of proximity to the east-west trunk line of the Santa Fe Railroad through Gallup to supply electric utilities in Arizona and elsewhere. Coal deposits in the central portion of the coalfield are inconvenient to either the railroad or the San Juan River.

The San Juan Basin (Table XXVII) continues to provide the entire New Mexico strip-coal production. The far western utility market for

TABLE XXVI

STRIPPABLE RESERVES AND RELATED CHARACTERISTICS BY STATE
(MILLION SHORT TONS)

Montana (Subbituminous)

1. By region and seam

REGION	SEAM	AVG. BED THICKNESS	RECOVERABLE STRIP RESOURCE	STRIPPABLE RESERVE	SULFUR CONTENT (L, M, H)
Fort Union	Dietz	50 ft.	1,016	640	(L) 640
Fort Union	Dietz #1	12 ft.	265	132	(L) 132
Fort Union	Anderson-Smith	25 ft.	66	66	(L) 66
Fort Union	Smith	29 ft.	640	182	(L) 182
Fort Union	Anderson	22 ft.	800	400	(L) 400
Fort Union	Roland	7 ft.	251	126	(L) 126
Fort Union	Knoblock	14 ft.	472	224	(M) 224
Fort Union	Knoblock	40 ft.	915	608	(L) 608
Fort Union	Knoblock	20 ft.	368	167	(L) 167
Fort Union	Canyon	21 ft.	200	100	(L) 100
Fort Union	Brewster-Arnold	12 ft.	160	28	(L) 28
Fort Union	Rosebud	22 ft.	1,097	727	(L) 727
TOTALS		28 ft. (avg.)	6,250	3,400	3,400

2. By region and county

REGION	COUNTY	AVG. BED THICKNESS	RECOVERABLE STRIP RESOURCE	STRIPPABLE RESERVE
Fort Union	Big Horn	37 ft.	1,964	1,009
Fort Union	Custer	13 ft.	148	64
Fort Union	Powder River	26 ft.	2,493	1,405
Fort Union	Rosebud	21 ft.	1,645	922
TOTALS		28 ft. (avg.)	6,250	3,400

TABLE XXVI (Continued)

STRIPPABLE RESERVES AND RELATED CHARACTERISTICS BY STATE
(MILLION SHORT TONS)

Montana (Lignite)

1. By region and seam

REGION	SEAM	AVG. BED THICKNESS	RECOVERABLE STRIP RESOURCE	STRIPPABLE RESERVE	SULFUR CONTENT (L, M, H)
Fort Union	Flowers-Goodale	11 ft.	160	96	(L) 96
Fort Union	Flowers	8 ft.	16	6	(L) 6
Fort Union	Terret	10 ft.	168	80	(M) 80
Fort Union	Terret	9 ft.	352	172	(L) 172
Fort Union	E	25 ft.	73	73	(L) 73
Fort Union	Pust	13 ft.	197	109	(L) 109
Fort Union	Pust	25 ft.	180	180	(L) 180
Fort Union	S	16 ft.	819	410	(L) 410
Fort Union	Broadus	20 ft.	378	240	(L) 240
Fort Union	Pawnee	22 ft.	165	95	(L) 95
Fort Union	Sawyer	27 ft.	1,521	910	(L) 910
Fort Union	Fort Peck	5 ft.	91	73	(L) 73
Fort Union	Fort Kipp	9 ft.	174	131	(L) 131
Fort Union	(Unnamed)	25 ft.	480	360	(M) 360
Fort Union	Reserve	8 ft.	197	100	(M) 100
Fort Union	C	19 ft.	675	462	(L) 462
TOTALS		24 ft. (avg.)	5,646	3,497	3,497

TABLE XXVI. (Continued)

STRIPPABLE RESERVES AND RELATED CHARACTERISTICS BY STATE
(MILLION SHORT TONS)

Montana (Lignite)

2. By region and county

REGION	COUNTY	AVG. BED THICKNESS	RECOVERABLE STRIP RESOURCE	STRIPPABLE RESERVE
Fort Union	Custer	13 ft.	601	347
Fort Union	Dawson	25 ft.	180	180
Fort Union	McCone	16 ft.	819	410
Fort Union	Powder River	26 ft.	2,064	1,245
Fort Union	Richland	13 ft.	196	109
Fort Union	Roosevelt	7 ft.	265	204
Fort Union	Rosebud	10 ft.	168	80
Fort Union	Sheridan	21 ft.	677	460
Fort Union	Wibaux	19 ft.	676	462
TOTALS		24 ft. (avg.)	5,646	3,497

TABLE XXVII

STRIPPABLE RESERVES AND RELATED CHARACTERISTICS BY STATE
(MILLION SHORT TONS)

New Mexico (Subbituminous)

1. By region and formation

REGION	FORMATION	AVG. BED THICKNESS	RECOVERABLE STRIP RESOURCE	STRIPPABLE RESERVE	SULFUR CONTENT (L, M, H)
San Juan	Fruitland	11 ft.	2,566	2,418	(L) 2,418
San Juan	Mesa Verde	5 ft.	80	56	(L) 56
TOTALS		11 ft. (avg.)	2,646	2,474	2,474

2. By region and county

REGION	COUNTY	AVG. BED THICKNESS	RECOVERABLE STRIP RESOURCE	STRIPPABLE RESERVE
San Juan	San Juan	11 ft.	2,494	2,370
San Juan	McKinley	8	152	104
TOTALS		11 ft. (avg.)	2,646	2,474

low-sulfur coal may be expected to draw more heavily in the future upon the subbituminous strip-coal deposits in the southern part of the field.

6.1.5 North Dakota

Production of lignite declined from a peak of 3.3 million tons in 1950 to 2.3 million tons in 1958; it has since risen to 4.5 million tons in 1968. The entire production for 1968 was mined by strip methods at 22 operations in 11 counties in the western part of the state.

Based on data from publications, private companies and Government agencies, strippable lignite reserves were determined for deposits in 13 Williston basin counties, all of which are in the Northern Great Plains coal province. About two-thirds of the reserves are located in two large deposits on the southwestern flank of the basin with the remainder in smaller deposits on the eastern flank. Lignite beds lie principally in the Tongue River Member of the Fort Union Formation of Tertiary age. They are essentially flat-lying with dips generally less than one degree. The beds range in thickness from a fraction of an inch up to 25 feet with often two or more beds of mineable thickness in a particular area.

The economic limits assumed for strippable reserves include: five feet minimum thickness; 50 feet of overburden; a maximum stripping depth of 220 feet where multiple seams may be mined; and a minimum heating value of 6,000 BTU per pound. Reserves of uraniferous lignite deposits in southwestern North Dakota may be expected to continue in use only for recovery of uranium (and molybdenum); such deposits have been excluded as strip-lignite reserves. Strip-lignite reserves (Table XXVIII)were estimated at 2.1 billion tons.

TABLE XXVIII

STRIPPABLE RESERVES AND RELATED CHARACTERISTICS BY STATE
(MILLION SHORT TONS)

North Dakota (Lignite)

1. By region and seam

REGION	SEAM	AVG. BED THICKNESS	RECOVERABLE STRIP RESOURCE	STRIPPABLE RESERVE	SULFUR CONTENT (L, M, H)
Fort Union	C (Beach Deposit)	18 ft.	368	224	(L) 224
Fort Union	D (Dickerson Deposit)	15 ft.	335	210	(L) 210
Fort Union	E (Dickerson Deposit)	9 ft.	285	160	(L) 160
Fort Union	Harmon	24 ft.	995	375	(M) 375
Fort Union	Harmon	22 ft.	182	101	(L) 101
Fort Union	Harmon	19 ft.	248	158	(L) 158
Fort Union	Noonan	8 ft.	12	12	(L) 12
Fort Union	Bonus	9 ft.	40	17	(L) 17
Fort Union	Wilton	9 ft.	12	12	(L) 12
Fort Union	Niobe	6 ft.	77	32	(L) 32
Fort Union	Dunn	11 ft.	23	23	(L) 23
Fort Union	Beulah-Top	15 ft.	684	335	(L) 335
Fort Union	Stanton & Local	15 ft.	18	18	(L) 18
Fort Union	Stanton	9 ft.	80	24	(L) 24
Fort Union	Hagel-kenther	8 ft.	144	80	(L) 80
Fort Union	T-Cross	15 ft.	120	40	(L) 40
Fort Union	Hansen	15 ft.	160	133	(L) 133
Fort Union	Coreair	12 ft.	4	4	(L) 4
Fort Union	No. 1 (Avoca Deposit)	5 ft.	26	22	(M) 22
Fort Union	No. 2 (Avoca Deposit)	5 ft.	39	22	(L) 22
Fort Union	No. 3 (Avoca Deposit)	9 ft.	110	35	(L) 35
Fort Union	No. 4 (Avoca Deposit)	8 ft.	129	21	(L) 21
Fort Union	Top	12 ft.	80	17	(L) 17
TOTALS		16 ft. (avg.)	4,191	2,075	2,075

TABLE XXVIII (Continued)

STRIPPABLE RESERVES AND RELATED CHARACTERISTICS BY STATE
(MILLION SHORT TONS)

North Dakota (Lignite)

2. By region and county

REGION	COUNTY	AVG. BED THICKNESS	RECOVERABLE STRIP RESOURCE	STRIPPABLE RESERVE
Fort Union	Billings	11 ft.	106	66
Fort Union	Bowman	21 ft.	400	213
Fort Union	Burke	7 ft.	129	61
Fort Union	Burleigh	9 ft.	12	12
Fort Union	Dunn	11 ft.	111	41
Fort Union	Golden Valley	18 ft.	368	224
Fort Union	Mercer	15 ft.	641	312
Fort Union	Oliver	10 ft.	205	121
Fort Union	Slope	22 ft.	1,305	594
Fort Union	Stark	12 ft.	446	286
Fort Union	Ward	12 ft.	4	4
Fort Union	McLean	9 ft.	80	24
Fort Union	Williams	9 ft.	384	117
TOTALS		16 ft. (avg.)	4,191	2,075

6.1.6 South Dakota

South Dakota lignite production reached a peak of 71 thousand tons in 1941. However, production has declined to a few thousand tons in recent years. Lignite has been used locally for fuel, and production from some beds has been treated for the recovery of uranium.

Lignite resources of South Dakota are located in the northwestern part of the state--an extension of the huge lignite deposits in North Dakota. South Dakota's total lignite resources have been estimated at 3 billion tons, occurring as beds of four to six feet in thickness in the Lance and Fort Union Formations of Tertiary age. Average calorific content is 6,000 BTU per pound; average sulfur content is less than 1 percent. Recoverable strip lignite reserves (Table XXIX) are estimated at 160 million tons under less than 100 feet of overburden.

6.1.7 Utah

No strip-coal production has been recorded in the state in nearly 50 years; however, about 40,000 tons were extracted in a strip operation at Scofield, Carbon County, about 1920. Other small tonnages have since been mined from coal outcrops for local use, but nearly all production to date has been mined underground. Production reached a peak of 7.4 million tons in 1947.

Deposits near Alton in the Kanab field in the southwestern part of the state appear favorable for large-scale strip mining. However, markets must be established before the deposits can be developed. Known strip coal reserves are long distances from railroads. The Kanab field is

TABLE XXIX

STRIPPABLE RESERVES AND RELATED CHARACTERISTICS BY STATE
(MILLION SHORT TONS)

South Dakota (Lignite)

1. By region

REGION	AVG. BED THICKNESS	RECOVERABLE STRIP RESOURCE	STRIPPABLE RESERVES	SULFUR CONTENT (L, M, H)
Fort Union	5 ft.	319	160	(L) 160

45 miles southeast of the railroad terminal at Cedar City. Serviceable roads connect the deposits to Cedar City.

The Kanab coalfield contains the largest known reserves of strip coal in the state. These occur in one of two prominent coalbeds in the Cretaceous Tropic Formation. The upper coalbed is about 400 feet above the lower and is considered strippable where overburden is 10 to 60 feet. Average mineable coal thickness of the upper seam is 11 feet. Smaller blocks of strippable coal are present in areas more remote from major markets than the Kanab field. However, reserves in these areas are generally too small to support the construction of a railroad or slurry pipeline. Strippable reserves (Table XXX) in Utah have been estimated at 150 million tons of bituminous coal.

6.1.8 Wyoming

Coal production reached a peak of 9.8 million tons in 1945. A decline followed to a low of 1.6 million tons in 1958. Output has since increased to over 7 million tons in 1970. Strip-mined coal amounted to 0.2 million tons or 3 percent of production in 1940; by 1968, the portion of production that was stripped had increased to 97 percent of the state's output. Stripping operations are widely scattered with nine pits in seven widely scattered counties.

Most significant strip coal deposits are of the Tertiary age in the northeastern part of the state; they include the 30- to 130-foot thick Roland coalbed and the 10- to 40-foot thick Felix coalbed. These two coalbeds crop out for more than 100 miles along the east flank of the Powder River Basin and contain a major part of the state's strippable reserves.

TABLE XXX

STRIPPABLE RESERVES AND RELATED CHARACTERISTICS BY STATE
(MILLION SHORT TONS)

Utah (Bituminous)

1. By region and formation

REGION OR FIELD	FORMATION	AVG. BED THICKNESS	RECOVERABLE STRIP RESOURCE	STRIPPABLE RESERVE	SULFUR CONTENT (L, M, H)
Uinta	Ferron	5 ft.	8	6	(L) 6
Henry Mountains	Ferron	7 ft.	14	8	(H) 8
Kaiparowits-Harmony	Christenson Zone	50 ft.	19	16	(M) 16
Kaiparowits-Harmony	Tropic 1	11 ft.	160	120	(M) 120
TOTALS		14 ft. (avg.)	201	150	150

2. By region and county

REGION OR FIELD	COUNTY	AVG. BED THICKNESS	RECOVERABLE STRIP RESOURCE	STRIPPABLE RESERVE
Uinta	Emery-Sevier	5 ft.	8	6
Henry Mountains	Wayne	7 ft.	14	8
Kaiparowits-Harmony	Garfield	50 ft.	19	16
Kaiparowits-Harmony	Kane	11 ft.	160	120
TOTALS		14 ft. (avg.)	201	150

At Lake DeSmet, near Buffalo, on the west flank of the Powder River Basin, a coalbed averages more than 100 feet in thickness and locally may be as much as 220 feet thick; it underlies an area of several square miles and contains a strippable deposit of more than 1 billion tons. On the south flank of the basin in Converse County, the 35-foot thick School and 20-foot thick Badger coalbeds contain available strippable reserves exceeding 45 million tons. Estimated available strip coal reserves (Table XXXI) for the state are estimated at 14 billion tons.

6.2 Characteristics of Rocky Mountain Coal

In order to estimate the coal reserves in each sulfur category, it was necessary to build a data base of coal analyses. It was assumed that these analyses would be representative of the coal reserves and, therefore, could be used to distribute reserves into the various sulfur categories. Details of the data base comprising 1959 individual coal analyses, the related computer program, and the various program input items are provided in Appendix III. In addition, a list of references for the Western Coal analyses used in the data base is included in Appendix III.

As stated in Appendix III the computer program could categorize by several different criteria and compute basic statistical date on the data base of 1,959 samples. For this study, the data was categorized in only four different ways. This breakdown was by:

- coal rank only
- coal rank and state
- coal rank, state, and region
- coal rank, state, region, and sulfur content

TABLE XXXI

STRIPPABLE RESERVES AND RELATED CHARACTERISTICS BY STATE
(MILLION SHORT TONS)

Wyoming (Subbituminous)

1. By region and seam

REGION	SEAM	AVG. BED THICKNESS	RECOVERABLE STRIP RESOURCE	STRIPPABLE RESERVE	SULFUR CONTENT (L, M, H)
Powder River	Canyon	20 ft.	148	148	(L) 148
Powder River	Roland-Smith	71 ft.	12,880	11,800	(L) 11,800
Powder River	Felix	12 ft.	384	192	(L) 192
Powder River	Smoth-Local	10 ft.	189	94	(L) 94
Green River	B-C	25 ft.	134	93	(H) 93
Powder River	D-E	35 ft.	400	160	(H) 160
Powder River	Healy	130 ft.	1,600	800	(L) 800
Powder River	Monarh	23 ft.	40	40	(L) 40
Powder River	F	8 ft.	144	48	(H) 48
Green River	Hanna Form (8 seams)	10 ft.	8	8	(L) 8
Powder River	School	32 ft.	80	38	(L) 38
Powder River	Badger	18 ft.	29	7	(L) 7
Green River	Adaville (13 seams)	20 ft.	800	140	(L) 140
Green River	Ft. Union Form (2 seams)	15 ft.	200	110	(L) 110
Green River	Battle 2 & 3	7 ft.	30	15	(M) 15
Green River	Sourdough	8 ft.	368	184	(H) 184
Green River	Hadsell 2	8 ft.	32	16	(H) 16
Green River	Creston 2 & 3	18 ft.	100	50	(M) 50
Green River	Latham	6 ft.	56	28	(H) 28
TOTALS		67 ft (avg.)	17,622	13,971	13,971

TABLE XXXI (Continued)

STRIPPABLE RESERVES AND RELATED CHARACTERISTICS BY STATE
(MILLION SHORT TONS)

2. By region and county

REGION	COUNTY	AVG. BED THICKNESS	RECOVERABLE STRIP RESOURCE	STRIPPABLE RESERVE
Powder River	Campbell	68 ft.	13,527	12,160
Powder River	Converse	25 ft.	653	253
Powder River	Johnson	130 ft.	1,600	800
Powder River	Sheriden	21 ft.	114	114
Green River	Carbon	24 ft.	142	101
Green River	Lincoln	20 ft.	800	140
Green River	Sweetwater	11 ft.	786	403
TOTALS		67 ft. (avg.)	17,622	13,971

6.2.1 Proximate Analysis of Rocky Mountain Coals

Basic statistical data was first computed for the samples broken down by rank and by state and rank. The minimum value, maximum value, average, and standard deviation of the moisture content; volatile matter quantity; fixed carbon content; ash content; total, pyritic, and organic sulfur content; BTU value; and grindability index were computed for all the bituminous, subbituminous, and lignite coal samples and for the coal samples of each Rocky Mountain state in each rank. The volatile matter, fixed carbon content, ash content, and sulfur content were all on a dry weight percent basis. The results for the breakdown by rank only are shown in Table XXXII. The results for only the total sulfur content are further broken down by state in Table XXIII.

The data presented in Tables XXXII and XXXIII are historical and the provided averages are based on the number of indicated samples. Due to the limited sampling and possible geographic sampling bias, the numbers may not represent the coal in place and therefore should be used with caution.

6.2.2 Regional Characteristics of Rocky Mountain Coal

The data base was also categorized by each region in each state for each rank for which analyses existed. The minimum value, maximum value, average, and standard deviation of the coal analyses were computed for each of the 38 categorizations. An example of the computer printouts (e.g. the subbituminous coal in the Powder River

TABLE XXXII

ROCKY MOUNTAIN REGION COAL CHARACTERISTICS

		Avg.	Std. Dev.	No. of Samples
I.	Bituminous Coal			
	Moisture Content (wt.%)	7.7	3.49	1210
	Volatile Matter (wt.% dry)	40.3	4.24	949
	Fixed Carbon (wt.% dry)	51.4	3.78	949
	Ash (wt.% dry)	8.0	4.33	1210
	Total Sulfur (wt.% dry)	0.92	0.96	1210
	Pyritic Sulfur (wt.% dry)	0.29	0.53	261
	Organic Sulfur (wt.% dry)	0.60	0.43	261
	Grindability Index	50	8.6	107
	BTU/lb As Received	11,879	956.1	949
II.	Subbituminous Coal			
	Moisture Content (wt.%)	19.6	5.79	527
	Volatile Matter (wt.% dry)	40.0	3.72	359
	Fixed Carbon (wt.% dry)	51.0	4.82	359
	Ash (wt.% dry)	8.4	5.20	526
	Total Sulfur (wt.% dry)	0.80	0.71	527
	Pyritic Sulfur (wt.% dry)	0.22	0.30	168
	Organic Sulfur (wt.% dry)	0.53	0.53	168
	Grindability Index	51	9.2	30
	BTU/lb As Received	9,235	939.2	359
III.	Lignite Coal			
	Moisture Content (wt.%)	36.8	4.72	221
	Volatile Matter (wt.% dry)	42.7	3.78	193
	Fixed Carbon (wt.% dry)	46.5	5.02	193
	Ash (wt.% dry)	10.5	3.61	221
	Total Sulfur (wt.% dry)	0.96	0.58	221
	Pyritic Sulfur (wt.% dry)	0.15	0.26	28
	Organic Sulfur (wt.% dry)	0.58	0.35	28
	Grindability Index	48	10.2	43
	BTU/lb As Received	6,763	522.9	193

TABLE XXXIII

SULFUR CHARACTERISTICS STATISTICS FROM ANALYSES OF ROCKY MOUNTAIN REGION COAL SAMPLES
(% by wt. dry)

	Min.	Avg.	Max.	Std. Dev.	No. Samples
I BITUMINOUS COAL					
Arizona	.40	.79	1.30	.31	13
Colorado	.20	.78	5.10	.55	561
Montana	.40	2.16	10.30	1.94	110
New Mexico	.40	.97	4.60	.82	89
Utah	.30	.83	6.67	1.08	231
Wyoming	.30	.71	1.60	.23	206
	.20	.92	10.30	.96	1210
II. SUBBITUMINOUS COAL					
Arizona	.40	1.32	2.30	.73	8
Colorado	.24	.49	2.42	.26	171
Montana	.30	1.19	6.10	1.02	136
New Mexico	.46	.78	1.54	.35	14
Utah	.51	1.90	6.74	1.74	12
Wyoming	.18	.70	2.70	.32	185
	.18	.80	6.74	.71	526
III. LIGNITE					
Montana	.30	.94	3.20	.67	65
North Dakota	.29	.98	2.80	.55	144
	.29	.96	3.20	.58	209

Region in Wyoming) is presented in Appendix III. We have on file the other 37 tables of results for this type of categorization. Each of these categorizations was then broken down by sulfur content. The basic statistics were computed for the samples of each rank in each state for each region with a sulfur content, on a dry weight percent basis, of 0-0.49%, 0.50-0.69%, 0.70-0.99%, 1.00-1.49%, 1.50-1.99%, 2.0-2.49%, 2.50-2.99%, and those greater than 3.00%. An example of this (again for the subbituminous coal in the Powder River Region of Wyoming) is also provided in Appendix III. And again, we have on file the other 296 tables of results for this type of categorization. It should be noted that when only one sample fell in some category and the standard deviation was thus undefined, the computer was instructed to flag this result by printing a negative output.

From these results, the percentage of samples in each sulfur category was calculated for each coal rank in each region in each state for which we had samples. These results are presented in Table XXXIV.

Distributions of coal reserves by sulfur content were based on the samples collected in each region. Sample distribution data were applied to the strippable coal reserves determined by the Bureau of Mines, as listed in Table XXIV through XXXI in section 6.1 of this report. The results of this are shown in Tables XXXIV and XXXV. It should be noted that, the Bureau of Mines had made some

TABLE XXXIV

PERCENT OF SAMPLES IN EACH SULFUR CATEGORY (DRY BASIS)[1]

STATE, REGION, RANK	TOTAL NO. SAMPLES	0-0.49%	0.50 - 0.69%	0.70 - 0.99%	1.00 - 1.49%	1.50 - 1.99%	2.00 - 2.49%	2.50 - 2.99%	3.00+%
ARIZONA, BLACK MESA, BITUMINOUS	13	7.7	30.8	23.1	38.5	0	0	0	0
ARIZONA, BLACK MESA, SUBBITUMINOUS	8	25.0	12.5	0	0	50.0	12.5	0	0
COLORADO, GREEN RIVER, BITUMINOUS	81	16.0	46.9	9.9	14.8	0	11.1	1.2	0
COLORADO, GREEN RIVER, SUBBITUMINOUS	24	50.0	37.5	12.5	0	0	0	0	0
COLORADO, UINTA, BITUMINOUS	210	17.6	48.6	28.1	3.3	1.4	0.5	0	0
COLORADO, UINTA, SUBBITUMINOUS	20	10.0	50.0	35.0	0	5.0	0	0	0
COLORADO, SAN JUAN RIVER, BITUMINOUS	71	1.4	14.1	39.4	12.7	14.1	5.6	4.2	8.5
COLORADO, DENVER, SUBBITUMINOUS	100	87.0	12.0	1.0	0	0	0	0	0
COLORADO, CANON CITY, BITUMINOUS	96	28.1	39.6	10.4	13.5	5.3	1.0	0	2.1
COLORADO, CANON CITY, SUBBITUMINOUS	20	35.0	35.0	10.0	10.0	5.0	5.0	0	0
COLORADO, RATON MESA, BITUMINOUS	103	2.9	72.8	24.3	0	0	0	0	0
COLORADO, RATON MESA, SUBBITUMINOUS	2	0	50.0	50.0	0	0	0	0	0
COLORADO, NORTH PARK-MIDDLE PARK, SUBBITUMINOUS	5	40.0	40.0	20.0	0	0	0	0	0
MONTANA, FT. UNION, SUBBITUMINOUS	42	16.7	21.4	26.2	28.6	0	4.8	2.4	0
MONTANA, FT. UNION, LIGNITE	50	12.0	24.0	22.0	22.0	8.0	4.0	6.0	2.0
MONTANA, RED LODGE, BITUMINOUS	31	3.2	6.5	6.5	22.6	29.0	16.1	9.7	6.5
MONTANA, RED LODGE, SUBBITUMINOUS	9	0	0	33.3	0	22.2	11.1	22.2	11.1
MONTANA, SOUTHWESTERN FIELDS, BITUMINOUS	11	27.3	36.4	27.3	9.1	0	0	0	0
MONTANA, SOUTHWESTERN FIELDS, SUBBITUMINOUS	5	0	20.0	20.0	20.0	20.0	20.0	0	0
MONTANA, BULL MOUNTAIN, BITUMINOUS	25	24.0	60.0	12.0	4.0	0	0	0	0
MONTANA, BULL MOUNTAIN, SUBBITUMINOUS	18	27.8	22.2	22.2	27.8	0	0	0	0
MONTANA, NORTH CENTRAL, BITUMINOUS	43	0	2.3	2.3	4.7	9.3	7.0	7.0	67.4
MONTANA, NORTH CENTRAL, SUBBITUMINOUS	59	0	6.8	49.2	23.7	3.4	3.4	0	13.6
NEW MEXICO, SAN JUAN RIVER, BITUMINOUS	71	1.4	26.8	53.5	5.6	1.4	0	4.2	7.0
NEW MEXICO, SAN JUAN RIVER, SUBBITUMINOUS	14	21.4	42.9	7.1	21.4	7.1	0	0	0
NEW MEXICO, RATON MESA, BITUMINOUS	17	0	47.1	47.1	5.9	0	0	0	0
NORTH DAKOTA, FT. UNION, LIGNITE	144	17.4	16.7	22.2	25.0	12.5	4.2	2.1	0
UTAH, UINTA, BITUMINOUS	223	26.5	46.6	17.0	6.3	1.8	1.8	0	0
UTAH, KAIPAROWITS-HARMONY, BITUMINOUS	8	0	0	0	0	0	0	0	100
UTAH, KAIPAROWITS-HARMONY, SUBBITUMINOUS	6	0	33.3	16.7	0	16.7	0	0	33.3
WYOMING, GREEN RIVER, BITUMINOUS	128	4.7	11.7	71.1	11.7	0.8	0	0	0
WYOMING, GREEN RIVER, SUBBITUMINOUS	52	1.9	21.2	53.8	19.2	3.8	0	0	0
WYOMING, WIND RIVER, SUBBITUMINOUS	11	0	27.3	72.7	0	0	0	0	0
WYOMING, BIG HORN, BITUMINOUS	24	12.5	62.5	25.0	0	0	0	0	0
WYOMING, BIG HORN, SUBBITUMINOUS	10	30.0	40.0	30.0	0	0	0	0	0
WYOMING, HANNA, BITUMINOUS	54	55.6	22.2	22.2	0	0	0	0	0
WYOMING, HANNA, SUBBITUMINOUS	6	33.3	33.3	16.7	16.7	0	0	0	0
WYOMING, POWDER RIVER, SUBBITUMINOUS	105	25.7	44.8	23.8	2.9	1.0	1.0	1.0	0

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[1] These distributions may or may not be representative of tonnage in place.

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preliminary estimates of the sulfur content of these strippable reserves. They had classified the sulfur content of these reserves as low, medium, or high, which corresponds to a sulfur content by weight of less than 1%, 1-2%, and greater than 2% respectively.

TABLE XXXV

ROCKY MOUNTAIN STRIPPABLE COAL RESERVES BY STATE, REGION, AND SULPHUR CONTENT

ARIZONA

Subbituminous

	Sulfur Content (wt. % dry)								Number of Analyses
	<0.5	0.5-0.7	0.7-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	>3.0	
Black Mesa Region	96.25	48.125	0	0	192.50	48.125	0	0	8

(in million tons)

TABLE XXXV (CONTINUED)

ROCKY MOUNTAIN STRIPPABLE COAL RESERVES BY STATE, REGION, AND SULFUR CONTENT

COLORADO

Bituminous

	Sulfur Content (wt. % dry)								
Region	<0.5	0.5-0.7	0.7-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	>3.0	Number of Analyses
Uinta	23.61	65.09	37.65	4.47	1.91	0.64	0	0.64	210
Green River	52.96	154.81	32.59	48.89	0	36.67	4.07	0	81
San Juan River	0.39	3.94	11.04	3.55	3.94	1.58	1.18	2.37	71

(in million tons)

TABLE XXXV (CONTINUED)

ROCKY MOUNTAIN STRIPPABLE COAL RESERVES
BY STATE, REGION, AND SULFUR CONTENT

MONTANA

	Sulfur Content (wt. % dry)								Number of Analyses
	<0.5	0.5-0.7	0.7-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	>3.0	
Fort Union Region									
a. Lignite	419.64	839.28	769.34	769.34	279.76	139.88	209.82	69.94	50
b. Subbituminous	566.66	728.55	890.46	971.41	0	161.87	8.92	0	42

(in million tons)

TABLE XXXV (CONTINUED)

ROCKY MOUNTAIN STRIPPABLE COAL RESERVES BY STATE, REGION, AND SULFUR CONTENT

NEW MEXICO

Subbituminous

	Sulfur Content (wt. % dry)								
	<0.5	0.5-0.7	0.7-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	>3.0	Number of Analyses
San Juan River Region	530.13	1060.28	176.69	530.13	176.69	0	0	0	14

(in million tons)

TABLE XXXV (CONTINUED)

ROCKY MOUNTAIN STRIPPABLE COAL RESERVES BY STATE, REGION, AND SULFUR CONTENT

NORTH DAKOTA

Lignite

	Sulfur Content (wt. % dry)								Number of Analyses
	<0.5	0.5-0.7	0.7-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	>3.0	
Fort Union Region	360.24	345.82	461.11	518.75	259.38	86.44	43.22	0	144

(in million tons)

TABLE XXXV (CONTINUED)

ROCKY MOUNTAIN STRIPPABLE COAL RESERVES BY STATE, REGION, AND SULFUR CONTENT

UTAH

Bituminous

Region	Sulfur Content (wt. % dry)								Number of Analyses
	<0.5	0.5-0.7	0.7-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	>3.0	
Uinta	1.59	2.80	1.02	0.38	0.11	0.11	0	0	223
Kaiparowits-Harmony	0	0	0	0	0	0	0	130	8

(in million tons)

TABLE XXXV (CONTINUED)

ROCKY MOUNTAIN STRIPPABLE COAL RESERVES BY STATE, REGION, AND SULFUR CONTENT

WYOMING

Subbituminous

Region	Sulfur Content (wt. % dry)								Number of Analyses
	<0.5	0.5-0.7	0.7-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	>3.0	
Powder River	3426.90	5965.30	3173.03	380.75	126.87	126.87	126.87	0	105
Green River	12.58	136.23	346.77	123.84	24.77	0	0	0	52

(in million tons)

7.0 COAL PRODUCTION GROWTH POTENTIAL

7.1 Raw Coal Growth Potential

Commercial steam coal production growth as a function of sulfur content is indicated in Table XXXVI. This table is based on the current 7% annual increase in production applied in each sulfur content category of estimated 1970 Eastern commercial steam coal production.(2,7) Using the 20-year reserve lifetime criteria, Table XXXVII describes the maximum annual production growth rate which the steam coal industry could practically achieve at each sulfur level based on known mineable (Category 1) reserves indicated in Table XVI.

7.1.1 Growth Criteria

The calculation of maximum annual production growth rate is based on the following equation:

$$G_{P_{max}} = \frac{R_T - (N \times P)}{N^2}$$

where $G_{P_{max}}$ = Maximum annual production growth rate (in tons)

R_T = Known mineable reserves (Category 1) (in tons)

N = Production reserve lifetime (20 years)

P = Current production.

This calculation assumes the following:

1. Production growth will not occur unless the existing production levels can be continued for 20 years.
2. All new annual production must be maintainable for 20 years.

TABLE XXXVI

CURRENT ANNUAL STEAM COAL PRODUCTION GROWTH

	WEIGHT PERCENT SULFUR CONTENT (Dry Basis)	ESTIMATED ANNUAL PRODUCTION GROWTH 10^6 TONS	10^{12} BTU
EASTERN U. S.	<0.7	1.5	39
	<1.0	5.0	130
	<1.5	7.0	182
	All Coal	26	680

TABLE XXXVII

ESTIMATED MAXIMUM ANNUAL STEAM COAL PRODUCTION GROWTH BASED ON RESERVES

	WEIGHT PERCENT SULFUR CONTENT (Dry Basis)	MAXIMUM ANNUAL PRODUCTION GROWTH 10^6 TONS	10^{12} BTU
EASTERN U. S.*	<0.7	9.4	240
	<1.0	20.4	530
	<1.5	37	960
	All Coal	165	4300
WESTERN U. S.*	<0.7	60	1250
	<1.0	110	2300
	<1.5	111	2330
	All Coal	140	2940

* Based on total known recoverable bituminous and subbituminous reserves. These include reserves not currently owned by coal producers.

The earliest date at which the maximum production rate could be achieved in the Eastern U.S. coal sources is 1975. This is based on a four-year period to develop the new underground mines required for the extraction of Appalachian low-sulfur coals. On the other hand, the Western coal sources could probably achieve their maximum production rate by 1974, based on a three-year time period to develop new strip mines.

The reserves upon which the maximum annual Western coal production increase is based (Table XXXVII) are mineable bituminous and subbituminous coals. The sources considered are located in Arizona, Colorado, Montana, New Mexico, and Wyoming.(2,7)

7.2 Rocky Mountain Coal for Eastern Markets

Rocky Mountain strippable reserves of coal that are most attractive for servicing eastern markets are in the Montana-Wyoming area. These strippable bituminous coal beds east of the Continental Divide are located in the contiguous Fort Union region in Montana and the Powder River region in Wyoming. As indicated in Tables XXVI and XXXI, the less than 1% sulfur content (by weight) subbituminous strippable reserves in these two regions are conservatively estimated to be in excess of 16 billion short tons.

Strippable reserves as a function of maximum sulfur content are given in Table XXXVIII. These values are based on strippable reserve values as defined by the Bureau of Mines(15) and a sulfur content distribution obtained by analyzing 147 coal samples in our data base covering the addressed reserves. The maximum production growth rate

TABLE XXXVIII

FORT UNION AND POWDER RIVER STRIPPABLE SUBBITUMINOUS RESERVES AS A FUNCTION OF SULFUR CONTENT

SULFUR CONTENT (By wt., dry basis)	≤0.5%	≤0.7%	≤1.0%
Strippable Reserves (in billion tons)	3.99	10.69	14.75

The maximum growth rate based on a 20-year mining lifetime and the current production level is given in Table XXXVI. This annual growth potential could be made available to supply eastern markets.

TABLE XXXIX

MAXIMUM PRODUCTION GROWTH RATE VS. SULFUR CONTENT (SUBBITUMINOUS COAL: FORT UNION AND POWDER RIVER REGIONS)

SULFUR CONTENT (By wt., dry basis)	≤0.5%	≤0.7%	≤1.0%
Production Growth Potential (in million tons per year)	9.5	26.2	36.3

based on a 20 year mining lifetime and current production levels is given in Table XXXIX.

7.2.1 Strip Mine Development Cost

The economic acceptability of a strip mine depends upon favorable relationships between coal bed and overburden. Coal must be present in large enough quantities to justify the large capital expense for mining machinery. Overburden must be such that it can be easily removed by large machines and yet it must possess the characteristics required to stand unsupported in steep highwalls and spoil piles. The ratio of overburden to coal must be such that the coal may be removed economically, and the beds must be thick enough to be mined efficiently by the larger machines.

Information obtained from the United States Geological Survey and from railroads indicated that a mine development cost which covers land, exploration, analysis, and equipment including trucks should be no more than four million dollars per million tons per year mining capacity. For larger mines, development cost roughly increases proportionately with mine capacity. The cost of preparing the coal bed, including overburden removal, is normally included in mining cost.

The above cost values do not include the cost of any required railroad spur lines. Information from two railroads indicates that over reasonable terrain, a line will cost on the order of 170 thousand dollars per mile of track.

7.2.2 F. O. B. Coal Cost

One of the most significant factors in the recovery of the western coal industry has been the general reduction in cost to the consumer. Table XL is a tabulation of average coal costs per ton in the western states in 1960, 1967, and 1968. These figures are from the Minerals Yearbooks published annually by the U. S. Bureau of Mines and represent the average value per ton of coal F. O. B. the mine site. From this tabulation, it is seen that coal production in the West increased just over 60 percent from 1960 through 1967, and that the average cost per ton of coal at the mine substantially decreased in the same time period. Noteworthy is the fact that the average cost of coal obtained from principally strip-mining states (i.e., Montana, North Dakota, Wyoming) have the lowest cost per ton of coal with average cost decreasing from 1967 through 1968. Furthermore, due to favorable labor productivity in strip mines and the desire of coal producers to promote market acceptance, the fluctuations in Montana-Wyoming F. O. B. coal prices have continued to be restrained.

As previously indicated, production in the Rocky Mountain region is increasing at a rapid rate. New Rocky Mountain region mines scheduled to open during the 1970 through 1974 time period indicate an additional production capacity of 38.9 million tons of coal. This value includes an 11.3 million ton additional capacity for 1970. Table XLI indicates this new capacity by state and year.

TABLE XL

AVERAGE COST OF BITUMINOUS COAL AND LIGNITE IN THE WEST(10)

State	1960		1967		1968	
	Tons (Thousands)	Avg.Cost ($/Ton)	Tons (Thousands)	Avg.Cost ($/Ton)	Tons Thousands	Avg.Cost ($/Ton)
Colorado	3,607	5.85	5,439	4.76	5,558	4.82
Montana	313	3.79	371	2.68	519	2.34
New Mexico	295	5.93	3,463	3.65	3,429	3.94
North Dakota	2,525	2.29	4,156	1.92	4,487	1.78
Utah	4,951	6.53	4,175	5.82	4,316	5.77
Wyoming	2,024	2.45	3,588	3.31	3,829	3.16

TABLE XLI

CAPACITY OF NEW MINES IN ROCKY MOUNTAIN REGION FOR PERIOD OF 1970 THROUGH 1974 (IN MILLION TONS PER YEAR)(3)

State	1970	1971	1972	1973	1974	Total
Arizona	5.2				7.8	13.0
Montana			5.0			5.0
Utah	0.8			2.3		3.1
Wyoming	5.3	5.0	2.5	___	5.0	17.8
Total	11.3	5.0	7.5	2.3	12.8	38.9

7.3 Transportation of Coal

Coal is transported by a number of carrier conveyances. The principal carriers used for coal transportation are:

- Railroad
- Truck
- Water borne carrier
- Pipeline.

In practice the employed transportation conveyance is determined on the basis of economics. The endeavor to maximize economic gains is instrumental in selecting a given coal transportation mode for particular source/destination/volume parameters.

Often, more than one mode of transportation is used to convey coal from the mine to the consumer. Some coal is transported from the mine via railroad and subsequently transferred to a water borne carrier, either inland or tidewater. In other cases, coal is transported from the mine by truck and then transferred to railroad cars for further shipping.

The information in Table XLII was obtained from Reference 16 and indicates bituminous coal quantities shipped by various modes of transportation during the 1967 calendar year.

7.3.1 Railroads

Railroad Bulk Tariffs. Railroad bulk tariff rates apply to volume shipments usually with restrictions on the number of sources and the number of destination points. As an

TABLE XLII

MODES OF COAL TRANSPORTATION

(1967)

MODE	QUANTITY
Coal loaded for shipment by railroads (Includes class I, II, and private)*	404,525,000 tons
Revenue freight handled by class I railroads (originated-net tons)	376,706,934 tons
Unit train handling	102,330,000 tons
Domestic inland water movement	98,055,622 tons
Truck shipment	47,597,000 tons

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* Class I Railroad - one with operating revenue of five million dollars or more per year.

* Class II Railroad - one with operating revenue of less than five million dollars per year.

* Private Railroad - one owned by shipper.

illustration (i.e., indicative of existing conditions) bulk tariff rates have been designated "single car," rate A, rate B, rate C, and are defined as follows (in order of increasing cost):

- Rate A - 7000 ton train, all coal originating from not more than two origins using same assembly point.
- Rate B - 7000 ton train, coal originating from three or more origins using same assembly point.
- Rate C - Smaller train, 4500 tons from one or more origins using same assembly point.

Unit Trains. The unit train is a management technique that permits efficient planning through long-range contractual commitment of producer and consumer and dedication of the equipment. Specifically, a unit train consists of a dedicated set of haulage equipment loaded at one origin, unloaded at one destination each trip, and moving in both directions on a pre-determined schedule. Although the origin and destination are not necessarily the same for each trip, the shipment is never split for any trip.(17)

In terms of the tariff, or freight rate, a unit train is not a unit train until so designated by the carrier. Thus, the success of a unit train depends on cooperation between shipper, carrier, and consumer. In fixing tariff rates, the lowest cost usually is realized when a unit train is limited to a single-line haul. When more than one carrier is involved, additional capital cost and additional operating costs are reflected in the tariff rates. The tariff rates specify the haulage cost to the consumer on a net ton basis. Three parties, the railroad, producer, and the consumer, must negotiate the conditions and the rates (coal and transport) for unit train service.(17)

Reference 17, dated 1970 and published by the Bureau of Mines, contains a number of case studies on unit train transport cost and conditions. Information in Table XLIII was obtained from this study.

For shipping in railroad supplied cars, the cost of shipping varied between 0.54¢ and 0.78¢ per ton mile. Reference 18 confirmed the representativeness of the above-cited values. Values between 0.5¢ and 1.0¢ per ton mile should bracket all considered unit train haulage cost. The above rates assumed that all rolling stock is supplied by the railroads. Of course it should be realized that if rolling stock (cars) are supplied by either the producer or consumer, haulage rates payable to the railroads may be less. Even so, real haulage costs must consider the value of the provided rolling stock.

7.3.2 Truck Shipment

Reference 16 states that in 1967 over 47 million tons of coal were shipped by truck on public highways. Some trucks have capacities over 100 tons but, because of weight limitation on highways and bridges, are used only on mine roads. The trucks that haul coal directly to the final destination carry 10 to 20 tons, and the trips

TABLE XLIII

UNIT TRAIN CASE STUDIES(17)

MINE LOCATION	HAULAGE DISTANCE (ONE WAY/MI)	OWNERSHIP OF CARS	MINIMUM TONS PER SHIPMENT	HAULAGE COST PER TON MILE (CENTS)*
Illinois	279	Consumer	12,500	0.54
Illinois	306	Consumer	12,600	0.44
Illinois	354	Consumer	10,200	0.52
Penna.	180	Consumer	10,500	0.83
W. Va.	450	RR	7,000	0.78
Illinois	130	RR	7,000	0.77
Ky.	333	RR	7,000	0.54
Tenn.	457	Leased by Producer	10,000	0.38
Ky.	129	Leased by Producer	7,500	0.78
Ohio	317	Leased by Producer	8,200	0.52

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* Cost payable to railroad and includes rolling stock only in cases where railroad ownership is indicated.

usually are short, rarely exceeding 100 miles. The transportation cost for these short hauls are estimated to be between 3.0 and 7.0 cents per ton/mile depending on distance, traffic, load factor, and load/unload conditions. Average trucking costs, Figure 11, were obtained from Reference 19 with updating by information from the U.S. Bureau of Labor Statistics.

7.3.3 Water Borne Carriers

Barge Shipment of Coal. Excluding the Great Lakes, the United States has over twenty-five thousand miles of commercially navigable inland waterways. Reference 20 indicated that in 1968 almost 114 million tons of bituminous coal and lignite were transported on the inland waterways of the United States (exclusive of the Great Lakes).

Barge towing costs are indicated by Figure 12 and are based on information in Reference 19 as updated by information obtained from the U. S. Bureau of Labor Statistics.

Lake Carriers of Coal. In 1968 more than 44 million tons of coal were loaded into vessels at Lake Erie and Lake Ontario Ports.(16) The coal was shipped to these ports by rail for transshipment to coal carrying lake cargo ships. The coal is principally shipped to consumers contiguous to the lake with a large portion of the coal going to industries and utilities on the Canadian side of the border.

Due to the large distances between western coal sources and potential consumers, interest has developed in transshipping low sulfur western coals over the Greak Lakes. In essence, cost control

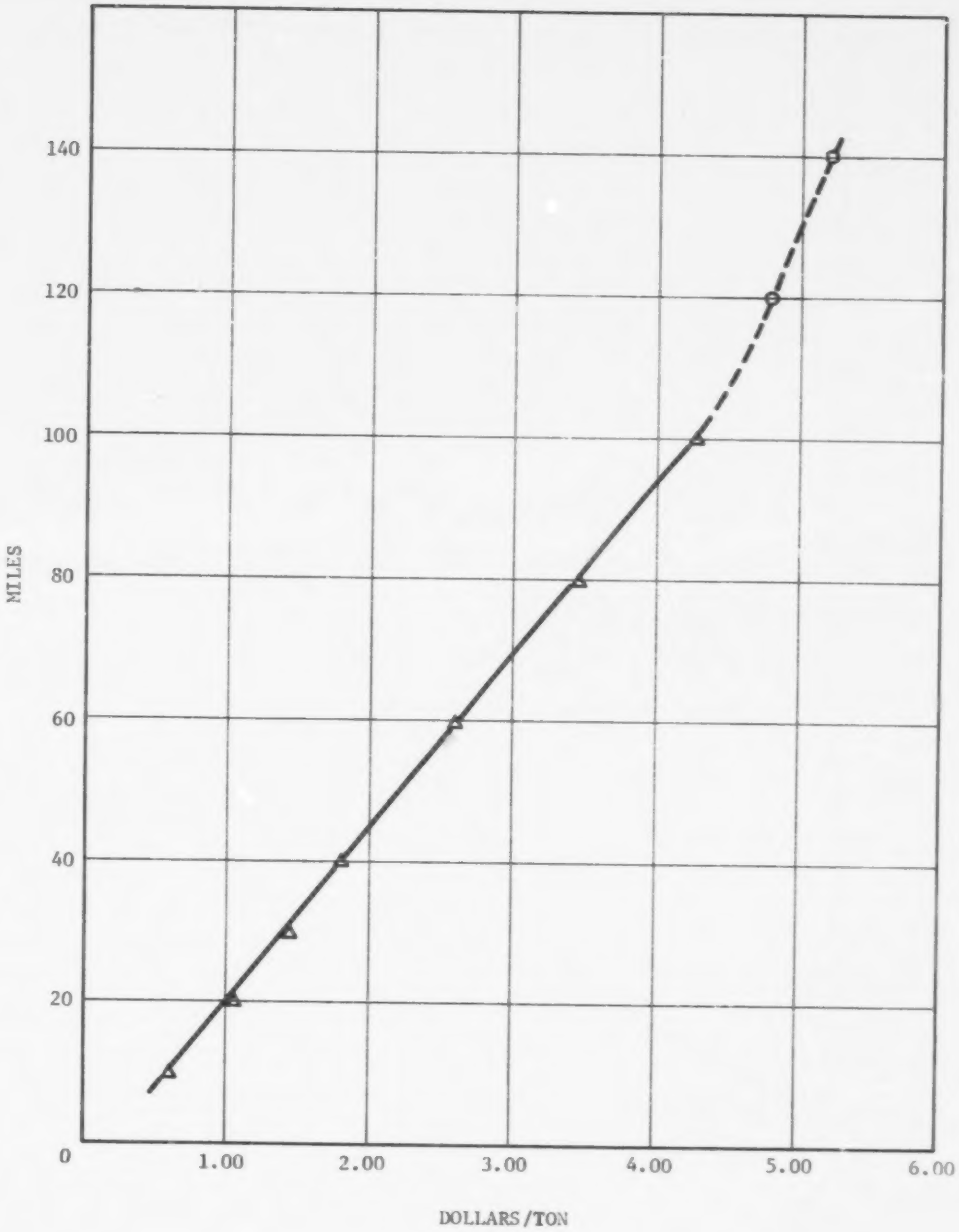

FIGURE II
ESTIMATED 1970 HAULAGE COSTS - PUBLIC HIGHWAY TRUCKING

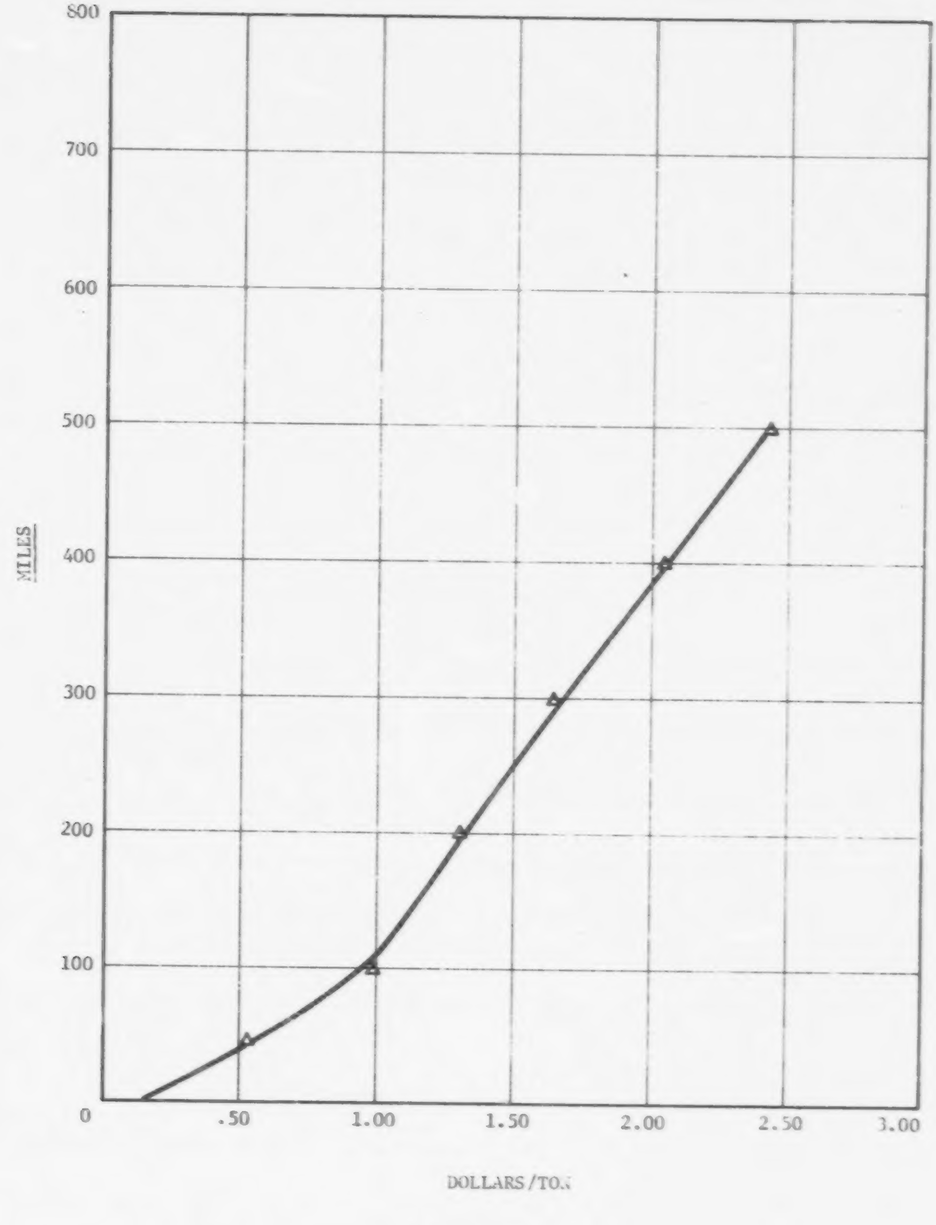

FIGURE 12
ESTIMATED 1970 BARGE TOWING COSTS–
OHIO RIVER AND TRIBUTARIES

is a principal consideration in encouraging the growth of low sulfur western steam coals for midwest markets. As a consequence, the western coal producers and the western railroads have attempted to provide western coals at acceptable costs.

The first shipment of low sulfur coal took place over the Burlington-Northern Allouez iron ore docks at Superior, Wisconsin on July 19, 1971.(21,22) For the test shipment, 5000 tons of coal from Peabody Coal Company's Big Sky Mine (at Colstrip, Montana) were moved in a 55-car train to the Superior ore docks for loading aboard the Sam Mather. The destination being the Erie Mining Company at Taconite Harbor, Minnesota. Based on rates for hauling iron ore from Duluth, Minnesota (near Superior) to the northern edge of Ohio, it is estimated that lake carrier rates for coal could stabilize between one-half and two-thirds unit train rates. Therefore, the transshipment of western coal from rail to lake carriers could reduce the delivered price of western coal to many potential midwest users and thereby further encourage the market for low sulfur Rocky Mountain coal.

7.3.4 Coal Pipelines (19,23)

Coal has been in the past and is presently moved by pipeline. In the past, the best known pipeline was the Consolidation Coal's 108 mile, 10 inch coal slurry line that extended from Cadiz, Ohio to Cleveland, Ohio. The Cadiz-Cleveland line paralleled a rail delivery system and, in fact, was initiated to compete with that system.

As rail delivery became more efficient and lower in cost per ton, the Cadiz-Cleveland pipeline was retired from competition. Even so, the technology that provided for its successful and sustained six-year operation provided the basis for the design and operation of the presently operating 273 mile Black Mesa pipeline.

The Black Mesa pipeline moves finely ground coal as a slurry in water 273 miles from the Black Mesa No. 1 Mine in northeastern Arizona to the Mojave Power Project in southern Nevada. The line moves slightly more than the equivalent of one and one-half unit trains per day.

The coal slurry is prepared in a plant located adjacent to the mine's coal handling facilities. The pipeline has an outside diameter of 18 inches for most of its length. This is reduced to 12 3/4 inches for the final 15 miles to "brake" the flow as the line drops steeply to the Colorado River valley near the Mojave Power Project.

At full capacity the slurry moves through the pipeline at about 5.8 feet per second or about 4 miles per hour. It takes a particle of coal 69 hours to travel the length of the pipeline. The pipeline holds about 17 million gallons of slurry containing about 42,000 tons of coal. At continuous flow it delivers almost 16,000 tons of coal daily which as previously indicated is slightly more than one and one-half unit trains (i.e., of 10,000 ton capacity). Comparison of the Cadiz-Cleveland and the Black Mesa pipelines are provided by Table XLIV.

TABLE XLIV

COMPARISON OF CADIZ-CLEVELAND AND BLACK MESA PIPELINES (23)

	CADIZ-CLEVELAND	BLACK MESA
Point of origin	Cadiz, Ohio	Kayenta, Ariz.
Point of termination	Cleveland, Ohio	Davis Dam, Nev.
Pipeline data:		
Length, miles	108	273
Pumping stations	3	4
Pipe diameter, OD, in.	10	18
Pumps:		
No. per station	3	3, except Sta. No. 2 which has 4
Manufacturer	U.S. Steel Oilwell Div.	U.S. Steel Oilwell Div.
Name	Wilson-Snyder	Wilson-Snyder
Type	Reciprocating, piston, double-acting duplex	Reciprocating, piston, double-acting duplex
Elec. motor drive, hp	450	1,750
Pump strokes per minute	30 to 49	0 to 65
Station spacing, miles	30 to 45	50 to 100
Operation:		
Flow rate, gpm	Approx. 1,100	Approx 4,300
Flow velocity, fps	4 to 6	About 5.4 in 18-in. pipe; about 11 in 12-in. pipe
Solids conc., percent wt.	50	45 to 50
Specific gravity of slurry	1.15 to 1.16	1.13 to 1.18
Particle size in slurry	Minus 1/8-in.	Minus 1/8-in.
Station manning:		
Station No. 1	4, 1/shift	4, 1/shift
Other stations, each	1, day shift	1, day shift
Notes	Delivery in 1959 and 1960 was 14% above expectations. Use factor was 96%	Delivery started late in 1970

1959 experience for the Cadiz-Cleveland pipeline with a rate of over one million tons of coal per year indicated a shipping cost between \$2.00 and \$2.25 per ton. The reported overall savings over (non-unit train) rail haulage was \$1.00 to \$1.25 per ton. This is an overall value including dewatering costs. With the arrival of the unit train shipping rates, shipping costs below those attained by the Cadiz-Cleveland pipeline were obtained and the pipeline was taken out of service.

For the Black Mesa pipeline/rail comparison, rail movement of coal would involve the building of 150 miles of new railroad and a total haul of 408 miles. The pipeline, with only 273 miles of travel, proved to be economically attractive for this particular application.

A general opinion in the coal industry is that with the exception of unusual conditions, and in light of unit train shipping rates, the cheapest way to move large volumes over land is by rail and rail transportation will continue to handle the bulk of our coal.

7.3.5 Transportation of Coal to Eastern Markets

Figure 10 is a map indicating the coal fields of the Rocky Mountains region with respect to the Continental Divide. In general, transportation problems increase substantially with proximity to the Continental Divide. The general topographic features of areas in proximity to the Divide often present impediments to the efficient moving of coal. As an example, in areas of Colorado, railway grade conditions are such as to impede large movement of coals in an easterly direction.

Figure 13 indicates the principal railroad service lines in the Rocky Mountain region. The relationships between coal reserves, topographic features, and rail service as shown by Figures 10 and 13 and Table X clearly indicate that coal from Montana-Wyoming is attractive for servicing eastern markets. From an economic standpoint, transportation of many western coals in the vicinity of or west of the Continental Divide may well be unacceptable.

Conversations with officials of two railroads serving the Rocky Mountain region did not indicate any major capacity problems associated with transporting large amounts of Montana-Wyoming region coals to more easterly markets.(22) The consensus is that considerable unused track capacity presently exists. Problem areas could develop in terminal areas. Potential problem areas are associated with the process of changing cars from one line to another, and the need for sidings of sufficient length to handle long unit trains. Even so, the railroads indicated that they are capable of handling and resolving such problems in the course of their business.

In the past, test shipments of coal have been sent from Gallop, New Mexico to a power plant in Hammond, Indiana, a distance of 1500 miles. This test by the Santa Fe Railroad was terminated after a couple of shipments. Santa Fe has also considered the transportation of Rocky Mountain region coal to ports in Galveston and Texas City,

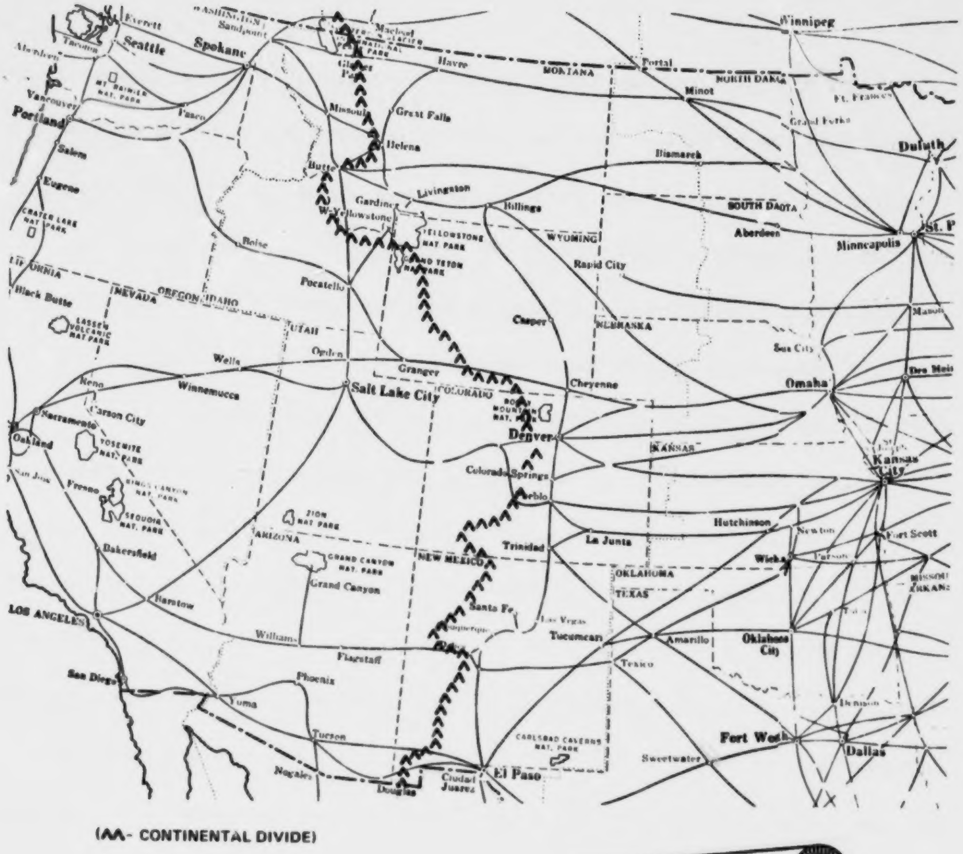
Everett
Seattle
Tacoma
Aberdeen
Spokane
WASHINGTON
Sandpoint
Macleod
GLACIER NATIONAL PARK
Glacier Park
Havre
MONTANA
Portal
Winnipeg
NORTH DAKOTA
Minot
Ft. Frances
Grand Forks
Duluth
MT RAINIER NAT. PARK
Vancouver
Portland
Pasco
Missoula
Great Falls
Helena
Bismarck
Salem
Butte
Eugene
Gardiner
Livingston
Billings
SOUTH DAOTA
St. P
W-Yellowstone
YELLOWSTONE NAT. PARK
Aberdeen
Minneapolis
CRATER LAKE NAT. PARK
Boise
WYOMING
GRAND TETON NAT PARK
Rapid City
Pocatello
CALIFORNIA
NEVADA
OREGON
IDAHO
Black Butte
Mason
LASSEN VOLCANIC NAT PARK
UTAH
Casper
NEBRASKA
Sux City
Wells
Ogden
Granger
Cheyenne
Omaha
Des Moi
Reno
Winnemucca
Salt Lake City
COLORADO
ROCKY MOUNTAIN NAT. PARK
Sacramento
Carson City
Oakland
YOSEMITE NAT. PARK
Denver
KANSAS
Kansas City
San Jose
Fresno
KINGS CANYON NAT. PARK
SEQUOIA NAT. PARK
Colorado Springs
Pueblo
ZION NAT PARK
Hutchinson
Newton
Fort Scott
ARIZONA
Trinidad
La Junta
Bakersfield
GRAND CANYON NAT. PARK
NEW MEXICO
Wichita
Grand Canyon
OKLAHOMA
TEXAS
Barstow
Santa Fe
Las Vegas
LOS ANGELES
Williams
Tucumcari
Amarillo
Oklahoma City
Flagstaff
Texico
San Diego
Phoenix
Yuma
Tucson
CARLSBAD CAVERNS NAT. PARK
Fort Worth
Sweetwater
Dallas
Nogales
Douglas
Ciudad Juarez
El Paso
(ʌʌ- CONTINENTAL DIVIDE)

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FIGURE 13

PRINCIPAL RAILROAD SERVICE LINES IN ROCKY MOUNTAIN REGION

Texas for reshipping via water carriers. In essence, even though some attention has been directed at shipping coals from the Rocky Mountain region, south of Wyoming, to eastern markets, such activities have been negligible.

In contrast, shipping activities of coals from the Montana-Wyoming area to eastern markets are sizeable and are continuing to increase. At the present, coal from the Montana-Wyoming area is being shipped to Grand Rapids and Duluth, Minnesota; Chicago and Joliet, Illinois; and Kansas City. In addition, present planning is considering possible deliveries to Madison, Wisconsin; Paducah, Kentucky; Detroit, Michigan; and Buffalo, New York via transfer from railroad cars to water carriers on the Great Lakes. Preliminary planning is also currently being directed at combination shipping concepts covering railroad transfer to either river or lake carriers. As an example, the Havana River terminal on the Illinois River is being considered as a barge transfer point. In essence, these dual carrier investigations are oriented to keeping overall transportation cost low, thus encouraging the development of coal traffic from Rocky Mountain region sources to eastern markets.

Information obtained from the railroads indicates that present shipments of western coals to eastern markets are not covered by long term contracts. Even so, all indications indicate that in order to obtain business and encourage economic growth, western coal is being hauled to eastern markets for rates in the vicinity of 4 to 7 mils per ton mile.

Existing unit trains operating in the Montana-Wyoming area have experienced some operating problems due to severe weather conditions. In general, the haulage process proceeds very well in ordinary weather, but problems are encountered in extremely cold weather. Problems that have been encountered in hauling Northern Rocky Mountain area coal to eastern markets include:

- The effect of prolonged cold weather on car dumping systems (e.g., ice accumulation on doors).
- Coal handling due to coal freeze-ups.

A potential problem for currently considered combination rail/waterway haulage concepts is that some northern waterways are subject to severe weather freeze-ups. The Mississippi River north of St. Louis as well as other northern waterways are subject to freeze-ups in severe winter weather. Therefore, such haulage by combined transportation modes must take into account the possibility of interrupted winter deliveries.

General transportation costs trends as a function of distance and mode of transportation are given by Figure 14.

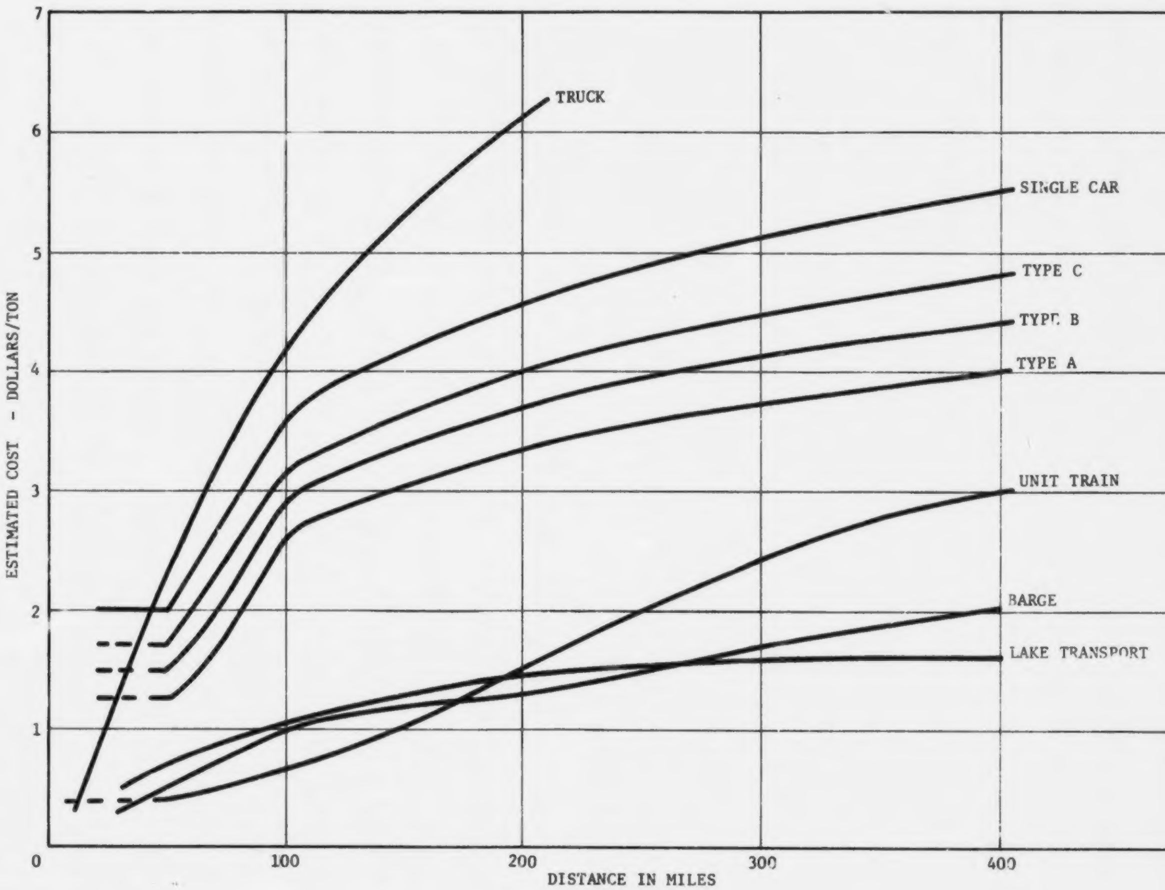

FIGURE 14
COAL TRANSPORTATION COSTS
GENERAL TREND, MODE VS. DISTANCE

8.0 PHYSICAL COAL DESULFURIZATION

The major possibility for increasing the low-sulfur production growth potential of Eastern steam coal sources in the near term is the physical desulfurization or "deep-cleaning" of coal. The physical desulfurization process involves first the crushing of the coal to release the pyritic sulfur and then the physical separation of the pyrite from the coal. Generally, the physical separation is based on the specific gravity difference between coal and the heavier pyrite particles. The practice of physically cleaning coal is a well-developed technology which has existed for many years. In the past the purpose has been to remove ash, thereby upgrading the quality of the coal. The process can be optimized for pyrite removal (i.e., physical desulfurization).(5)

Since the design and construction of a coal cleaning plant is estimated to be approximately three years, the lead time for opening of a new mine will not materially be affected by this addition.

The desulfurization process (as in most beneficiation processes) results in some loss in total heat content of the processed coal. Therefore, a balance must be achieved between the acceptable BTU loss and the increase in low sulfur coal. The potential increase in low sulfur coal was computed assuming the coal to be crushed to 3/8 inch top size and washed to an 85% minimum BTU yield. The results of this computation for bituminous coal are given in

Tables XLV through LIII. These tables give reserve and production figures distributed according to state and sulfur content.

The effect of desulfurization is to redistribute the coal to lower sulfur categories, giving a net increase in low sulfur coal. Redistribution was based on an examination of several hundred washability analyses performed on eastern coals for the Office of Air Programs.(24) Reserve and production figures were reassigned to the lower categories in the same proportion as were the analyses. The net effect of the desulfurization process on low sulfur coal availability is given in Table XLV. The general results of the cleanability estimate for steam coal production (of the Eastern Interior, Northern and Southern Appalachian coal regions) are indicated in Figure 15. The figures for total recoverable reserves (Table XLV) are based on the percent recoverable reserves given in Table XVI. In all cases the washed coal has been converted to a BTU equivalent amount assuming the average BTU yield to be 90%.

- Table XLVI gives the estimated coal reserves of the Eastern United States as of January 1, 1969 based on References 2 and 25.
- Table XLVII gives the same figures after washing.
- Table XLVIII gives coal production by sulfur level in the Eastern United States for 1968 based on References 2, 7, and 26.
- Table IL gives the estimated Appalachia mineable coal reserves by sulfur content controlled by operating companies as of January 1, 1968 based on References 2 and 7.

TABLE XLV

POTENTIAL INCREASE IN LOW SULFUR BITUMINOUS COAL (<1% SULFUR)
(3/8 in. topsize, Washed)
(Equivalent Tons of 90% BTU Yield)

REGION	INCREASE IN LOW SULFUR RESERVES (TONS)	INCREASE IN TOTAL RECOVERABLE LOW SULFUR RESERVES (TONS)	INCREASE IN LOW SULFUR MINEABLE RESERVES OWNED BY OPERATING COMPANIES (TONS)	INCREASE IN LOW SULFUR STEAM COAL PRODUCTION (TONS)
N. Appalachian	$34,290 \mathrm{x} 10^6$	$4,460 \mathrm{x} 10^6$	$1,480 \mathrm{x} 10^6$	$20 \mathrm{x} 10^6$
S. Appalachian	$7,100 \mathrm{x} 10^6$	$780 \mathrm{x} 10^6$	$320 \mathrm{x} 10^6$	$7 \mathrm{x} 10^6$
Eastern Interior (including Ohio)	$5,200 \mathrm{x} 10^6$	$1,300 \mathrm{x} 10^6$	$0 \mathrm{x} 10^6$*	$5 \mathrm{x} 10^6$
Total	$46,590 \mathrm{x} 10^6$	$6,540 \mathrm{x} 10^6$	$1,800 \mathrm{x} 10^6$	$32 \mathrm{x} 10^6$
% Increase Over Present (<1% S) Raw Coal Level	58%	58%	44%	56%

* Ohio only

TABLE XLVI

ESTIMATED REMAINING BITUMINOUS COAL RESERVES OF THE EASTERN UNITED STATES (1968)
(Million Tons)

	States / % Sulfur	0-.7	.8-1.0	1.1-1.5	1.6-2.0	2.1-2.5	2.6-3.0	3.1-3.5	3.6-4.0	>4.0	TOTAL
Northern Appalachian Region	Maryland	0.0	0.0	0.0	124.0	191.0	207.3	376.9	56.1	219.4	1,174.8
	Pennsylvania	43.8	1,148.1	7,582.6	12,356.8	19,581.7	9,940.8	5,258.6	1,144.2	577.4	57,634.1
	West Virginia	0.0	1,687.2	10,894.2	8,321.0	6,059.9	1,382.4	2,469.4	4,714.8	0.0	35,528.9
	TOTAL	43.8	2,835.3	18,476.8	20,801.8	25,832.6	11,530.5	8,104.9	5,915.1	796.8	94,337.6
Southern Appalachian Region	Alabama	885.2	1,184.0	5,397.3	5,159.5	456.7	415.5	0.0	0.0	18.5	13,516.8
	Kentucky	13,561.7	8,443.2	2,273.7	1,649.3	1,151.7	2,142.0	24.6	0.0	0.0	29,246.1
	Tennessee	3.2	158.5	705.3	254.9	175.6	187.7	216.4	43.1	67.5	1,812.3
	Virginia	1,952.6	5,988.8	1,613.2	0.0	122.1	0.0	0.0	0.0	0.0	9,676.7
	West Virginia	19,751.5	23,887.1	7,680.7	2,655.3	808.3	711.2	30.0	0.0	0.0	55,524.0
	TOTAL	36,154.2	39,661.6	17,670.2	9,719.0	2,714.4	3,456.4	271.0	43.1	86.0	109,775.9
Eastern Interior Region	Illinois	0.0	572.6	4,933.3	2,610.3	808.1	16,553.3	33,588.6	57,546.3	19,027.0	135,639.5
	Indiana	197.1	172.6	3,637.9	4,240.2	3,536.3	4,102.2	10,850.9	5,095.6	2,938.1	34,770.9
	Kentucky	0.0	0.0	1,113.2	161.1	334.4	3,771.8	12,686.1	13,565.0	5,052.1	36,683.7
	Ohio	0.0	609.3	368.0	2,104.3	2,742.7	7,788.7	9,758.0	10,119.9	8,415.9	41,906.8
	TOTAL	197.1	1,354.5	10,052.4	9,115.9	7,421.5	32,216.0	66,883.6	86,326.8	35,433.1	249,000.9
	GRAND TOTAL	36,395.1	43,851.4	46,199.4	39,636.7	35,968.5	47,202.9	75,259.5	92,285.0	36,315.9	453,114.4

TABLE XLVII

ESTIMATED REMAINING BITUMINOUS COAL RESERVES OF THE EASTERN UNITED STATES (1968) IF ALL HAD BEEN CRUSHED TO 3/8 INCH TOP SIZE AND WASHED (MILLIONS OF EQUIVALENT TONS OF 90% BTU YIELD)

	% Sulfur States	0-.7	.8-1.0	1.1-1.5	1.6-2.0	2.1-2.5	2.6-3.0	3.1-3.5	3.6-4.0	>4.0	TOTAL
Northern Appalachian	Maryland	10	120	320	290	140	100	40	20	10	1,050
	Pennsylvania	3,850	14,060	19,890	9,620	2,770	1,150	390	100	30	51,860
	West Virginia	6,070	13,060	13,020	5,670	2,150	940	710	280	0	41,900
	TOTAL	9,930	27,240	33,230	15,580	5,060	2,190	1,140	400	40	94,810
Southern Appalachian	Alabama	1,600	5,320	4,160	940	110	20	0	0	0	12,150
	Kentucky	14,690	7,150	2,360	1,550	480	100	0	0	0	26,330
	Tennessee	110	590	430	280	140	50	20	10	0	1,630
	Virginia	3,520	4,720	420	40	10	0	0	0	0	8,710
	West Virginia	24,920	20,300	3,620	910	190	30	0	0	0	49,970
	TOTAL	44,840	38,080	10,990	3,720	930	200	20	10	0	98,790
Eastern Interior	Illinois	260	2,710	4,350	21,870	35,840	28,210	18,520	8,600	1,710	122,070
	Indiana	260	2,100	4,930	8,040	7,550	4,490	2,690	990	260	31,310
	Kentucky	0	520	760	6,200	10,360	7,650	4,950	2,130	450	33,020
	Ohio	270	630	2,150	8,990	10,050	7,460	4,970	2,430	760	37,710
	TOTAL	790	5,960	12,190	45,100	63,800	47,810	31,130	14,150	3,180	224,110
	GRAND TOTAL	55,560	71,280	56,410	64,400	69,790	50,200	32,290	14,560	3,220	417,710

TABLE XLVIII

PRODUCTION OF BITUMINOUS COAL IN THE EASTERN UNITED STATES (1968)

(Thousand Tons)

	% Sulfur States	0-.7	.8-1.0	1.1-1.5	1.6-2.0	2.1-2.5	2.6-3.0	3.1-3.5	3.6-4.0	>4.0	TOTAL
Northern Appalachian Region	Maryland	0.0	110.7	176.9	241.4	917.9	0.0	0.0	0.0	0.0	1,447.0
	Pennsylvania	0.0	0.0	25,244.0	30,826.6	6,033.4	7,104.5	5,087.3	1,320.0	584.2	76,200.0
	West Virginia	0.0	0.0	15,444.0	7,031.7	13,298.9	8,963.7	4,517.8	4,734.8	0.0	53,991.0
	TOTAL	0.0	110.7	40,864.9	38,099.7	20,250.2	16,068.2	9,605.1	6,054.8	584.2	131,638.0
Southern Appalachian Region	Alabama	479.7	9,632.4	4,850.9	1,477.0	0.0	0.0	0.0	0.0	0.0	16,440.0
	Kentucky	39,933.1	9,454.5	3,518.1	1,687.2	285.1	0.0	0.0	0.0	0.0	54,878.0
	Tennessee	1,036.5	1,026.6	2,910.2	226.8	764.1	201.3	1,982.6	0.0	0.0	8,148.0
	Virginia	17,842.9	12,557.5	6,565.6	0.0	0.0	0.0	0.0	0.0	0.0	36,966.0
	West Virginia	62,994.9	25,097.0	2,613.6	470.2	754.2	0.0	0.0	0.0	0.0	91,930.0
	TOTAL	122,287.1	57,768.0	20,458.4	3,861.2	1,803.4	201.3	1,982.6	0.0	0.0	208,362.0
Eastern Interior Region	Illinois	0.0	0.0	6,954.2	11,822.6	0.0	4,805.6	15,356.4	13,731.0	9,771.1	62,441.0
	Indiana	137.4	0.0	4,402.2	0.0	3,790.8	85.7	0.0	9,009.7	1,060.2	18,486.0
	Kentucky	0.0	114.3	118.0	5,937.4	14,198.8	12,555.2	8,636.5	4,033.2	684.6	46,278.0
	Ohio	0.0	0.0	0.0	1,280.4	1,608.2	5,460.7	27,151.8	9,135.6	3,686.2	48,323.0
	TOTAL	137.4	114.3	11,474.4	19,040.4	19,597.8	22,907.2	51,144.7	35,909.5	15,202.1	175,528.0
	GRAND TOTAL	122,424.5	57,993.0	72,797.7	61,001.3	41,651.4	39,176.7	62,732.4	41,964.3	15,786.3	515,528.0

TABLE IL

ESTIMATED MINEABLE BITUMINOUS COAL RESERVES OF THE APPALACHIAN REGION OWNED BY OPERATING COMPANIES (1967)*

(Million Tons)

	States / % Sulfur	0-.7	.8-1.0	1.1-1.5	1.6-2.0	2.1-2.5	2.6-3.0	3.1-3.5	3.6-4.0	>4.0	TOTAL
Northern Appalachian Region	Maryland	0.0	0.0	0.0	0.6	0.8	0.9	1.7	0.3	1.0	5.2
	Pennsylvania	3.6	36.4	132.0	499.5	791.6	401.9	212.5	46.4	23.3	2,147.1
	West Virginia	0.0	0.0	1.8	1,428.3	1,040.0	237.2	424.2	809.2	0.0	3,940.7
	TOTAL	3.6	36.4	133.8	1,928.4	1,832.4	640.0	638.4	855.9	24.3	6,093.0
Southern Appalachian Region	Alabama	9.0	42.8	274.8	26.2	2.3	2.1	0.0	0.0	0.1	357.4
	Kentucky	280.4	274.6	248.2	110.5	77.2	143.4	1.6	0.0	0.0	1,135.8
	Tennessee	0.3	70.4	0.6	18.4	12.6	13.5	15.6	3.1	4.8	139.1
	Virginia	199.6	198.7	37.6	0.0	18.6	0.0	0.0	0.0	0.0	454.5
	West Virginia	776.4	2,154.0	368.1	184.5	56.4	49.4	1.9	0.0	0.0	3,590.7
	TOTAL	1,265.4	2,740.5	929.3	339.6	167.1	208.4	19.1	3.1	4.9	5,677.5
	Ohio	0.0	0.0	0.0	44.5	58.1	164.9	206.7	214.3	178.2	866.7
	GRAND TOTAL	1,269.0	2,776.9	1,063.1	2,312.5	2,057.6	1,013.3	864.2	1,073.3	207.4	12,637.2

*commercial and unassigned

- Table L gives the estimated reserves after washing to 90% BTU yield. Only the commercial and unassigned categories were considered since they constitute the major source of steam coal. The total coal reserves for Appalachia are shown in Table XVI.
- Table LI gives the 1967 production of steam coal in the Eastern United States based on References 2, 7, and 10.
- Table LII in an adjustment of Table LI to reflect sulfur reductions on washing.
- Table LIII is the estimated maximum annual steam production growth based on reserves, sulfur reductions on washing, current production levels, and a mine life of 20 years.

8.1 Cost/Benefit Analyses(5)

The essential variability of coal cleaning costs and benefits requires that economic evaluations be performed on an individual coal source/user case basis. Thirty potential physically desulfurized coal source/user combinations in the Eastern United States were chosen for the study (Reference 26) to provide an indication of the economic range associated with each cost and benefit factor. Coal source locations were limited to those indicating a potential, based on washability data, for physical desulfurization to a total sulfur content of 1% or less by weight at heat content yields of at least 75%. Table LIV summarizes the economic range associated with each assessable cost

TABLE L

ESTIMATED MINEABLE BITUMINOUS COAL RESERVES OF THE APPALACHIAN REGION OWNED BY OPERATING COMPANIES (1967)*
IF ALL HAD BEEN CRUSHED TO 3/8 INCH TOP SIZE AND WASHED
(MILLION OF EQUIVALENT TONS OF 90% BTU YIELD)

	%SULFUR / STATES	0 - .7	.8 - 1.0	1.1 - 1.5	1.6 - 2.0	2.1 - 2.5	2.6 - 3.0	3.1 - 3.5	3.6 - 4.0	>4.0	TOTAL
Northern Appalachian Region	Maryland	0	0	0	0	0	0	0	0	0	0
	Pennsylvania	100	490	770	390	110	50	20	0	0	1,930
	West Virginia	100	830	1,350	730	280	120	100	40	0	3,550
	TOTAL	200	1,320	2,120	1,120	390	170	120	40	0	5,480
Southern Appalachian Region	Alabama	40	190	80	0	0	0	0	0	0	310
	Kentucky	350	350	180	100	30	10	0	0	0	1,020
	Tennessee	10	60	20	20	10	0	0	0	0	120
	Virginia	240	150	20	10	0	0	0	0	0	420
	West Virginia	1,310	1,620	210	60	10	0	0	0	0	3,120
	TOTAL	1,950	2,370	510	190	50	10	0	0	0	5,080
	Ohio	0	0	40	190	210	160	100	50	20	770
	GRAND TOTAL	2,150	3,690	2,670	1,500	650	340	220	90	20	11,330

* commercial and unassigned

(all numbers rounded to nearest 10 million tons)

TABLE LI

PRODUCTION OF BITUMINOUS STEAM COAL IN THE EASTERN UNITED STATES IN 1967 (THOUSAND TONS)*

	% SULFUR STATES	0 - .7	.8 - 1.0	1.1 - 1.5	1.6 - 2.0	2.1 - 2.5	2.6 - 3.0	3.1 - 3.5	3.6 - 4.0	4.0 - 100	TOTAL
Northern Appalachian Region	Maryland	0.0	0.0	0.0	220.9	840.1	0.0	0.0	0.0	0.0	1,061.0
	Pennsylvania	56.7	1,572.4	3,197.6	19,874.4	3,890.4	4,578.1	3,276.4	849.8	378.2	37,674.0
	West Virginia	0.0	0.0	669.3	6,863.8	12,984.2	8,751.0	4,412.4	4,623.3	0.0	38,304.0
	TOTAL	56.7	1,572.4	3,866.9	26,959.1	17,714.7	13,329.1	7,688.8	5,473.1	378.2	77,039.0
Southern Appalachian Region	Alabama	0.0	2,266.8	548.3	5,521.9	0.0	0.0	0.0	0.0	0.0	8,337.0
	Kentucky	7,371.5	11,442.8	4,100.1	3,884.1	657.9	0.0	0.0	0.0	0.0	27,456.0
	Tennessee	0.0	1,527.7	773.6	212.4	716.7	188.7	1,858.9	0.0	0.0	5,278.0
	Virginia	3,784.2	3,972.6	814.0	832.6	0.0	0.0	0.0	0.0	0.0	9,403.4
	West Virginia	5,206.7	20,032.7	7,885.8	1,441.3	2,317.4	0.0	0.0	0.0	0.0	36,884.0
	TOTAL	16,362.4	39,242.6	14,121.8	11,892.3	3,692.0	188.7	1,858.9	0.0	0.0	87,358.4
Eastern Interior Region	Illinois	0.0	0.0	5,365.2	9,117.1	0.0	3,708.5	11,843.0	10,590.8	7,537.4	48,162.0
	Indiana	99.2	0.0	3,190.6	0.0	2,748.4	61.6	0.0	5,861.3	767.8	12,729.0
	Kentucky	0.0	0.0	209.6	0.0	17.1	0.0	11,594.2	24,616.8	6,325.3	42,763.0
	Ohio	0.0	0.0	112.6	877.0	1,102.0	3,739.5	18,595.0	6,257.9	2,525.0	33,209.0
	TOTAL	99.2	0.0	8,878.0	9,994.1	3,867.5	7,509.6	42,032.2	47,326.8	17,155.5	136,863.0
	GRAND TOTAL	16,518.3	40,815.0	26,866.7	48,845.5	25,274.2	21,027.4	51,579.9	52,799.9	17,533.7	301,260.4

*Commercial

TABLE LII

ESTIMATED PRODUCTION OF BITUMINOUS STEAM COAL IN THE EASTERN UNITED STATES IN 1967* IF ALL HAD BEEN CRUSHED TO 3/8 INCH TOP SIZE AND WASHED
(THOUSAND OF EQUIVALENT TONS OF 90% BTU YIELD)

	% SULFUR / STATES	0 - .7	.8 - 1.0	1.1 - 1.5	1.6 - 2.0	2.1 - 2.5	2.6 - 3.0	3.1 - 3.5	3.6 - 4.0	>4.0	TOTAL
Northern Appalachian Region	Maryland	20	280	460	160	40	0	0	0	0	960
	Pennsylvania	3,350	10,990	12,730	4,580	1,240	660	260	70	20	33,900
	West Virginia	690	6,960	13,500	8,490	2,800	1,210	610	210	0	34,470
	TOTAL	4,060	18,230	26,690	13,230	4,080	1,870	870	280	20	69,330
Southern Appalachian Region	Alabama	660	3,240	2,960	650	0	0	0	0	0	7,510
	Kentucky	10,090	10,690	3,210	670	50	0	0	0	0	24,710
	Tennessee	480	1,500	830	1,080	590	180	80	0	0	4,740
	Virginia	4,550	3,200	610	100	0	0	0	0	0	8,460
	West Virginia	10,800	17,730	3,560	940	170	0	0	0	0	33,200
	TOTAL	26,580	36,360	11,170	3,440	810	180	80	0	0	78,620
Eastern Interior Region	Illinois	0	3,230	7,850	7,510	9,400	7,360	5,010	2,310	680	43,350
	Indiana	100	1,440	1,980	2,240	1,920	1,800	1,260	670	70	11,480
	Kentucky	0	90	100	4,940	11,810	10,440	7,180	3,350	570	38,480
	Ohio	0	130	880	7,540	10,560	6,060	3,480	1,020	230	29,900
	TOTAL	100	4,890	10,810	22,230	33,690	25,660	16,930	7,350	1,550	123,210
	GRAND TOTAL	30,740	59,480	48,670	38,900	38,580	27,710	17,880	7,630	1,570	271,160

*Commercial (all numbers rounded to nearest 10 thousand tons)

TABLE LIII

ESTIMATED MAXIMUM ANNUAL STEAM COAL PRODUCTION GROWTH WITH PHYSICAL DESULFURIZATION

EASTERN U.S.

WEIGHT PERCENT SULFUR CONTENT (DRY BASIS)	MAXIMUM PRODUCTION WITH CLEANING	
	10^6 TONS	10^{12} BTU
< 0.7	12	314
<1.0	30	780
<1.5	75	2000
All Coal	180	4900

(In million tons per year)

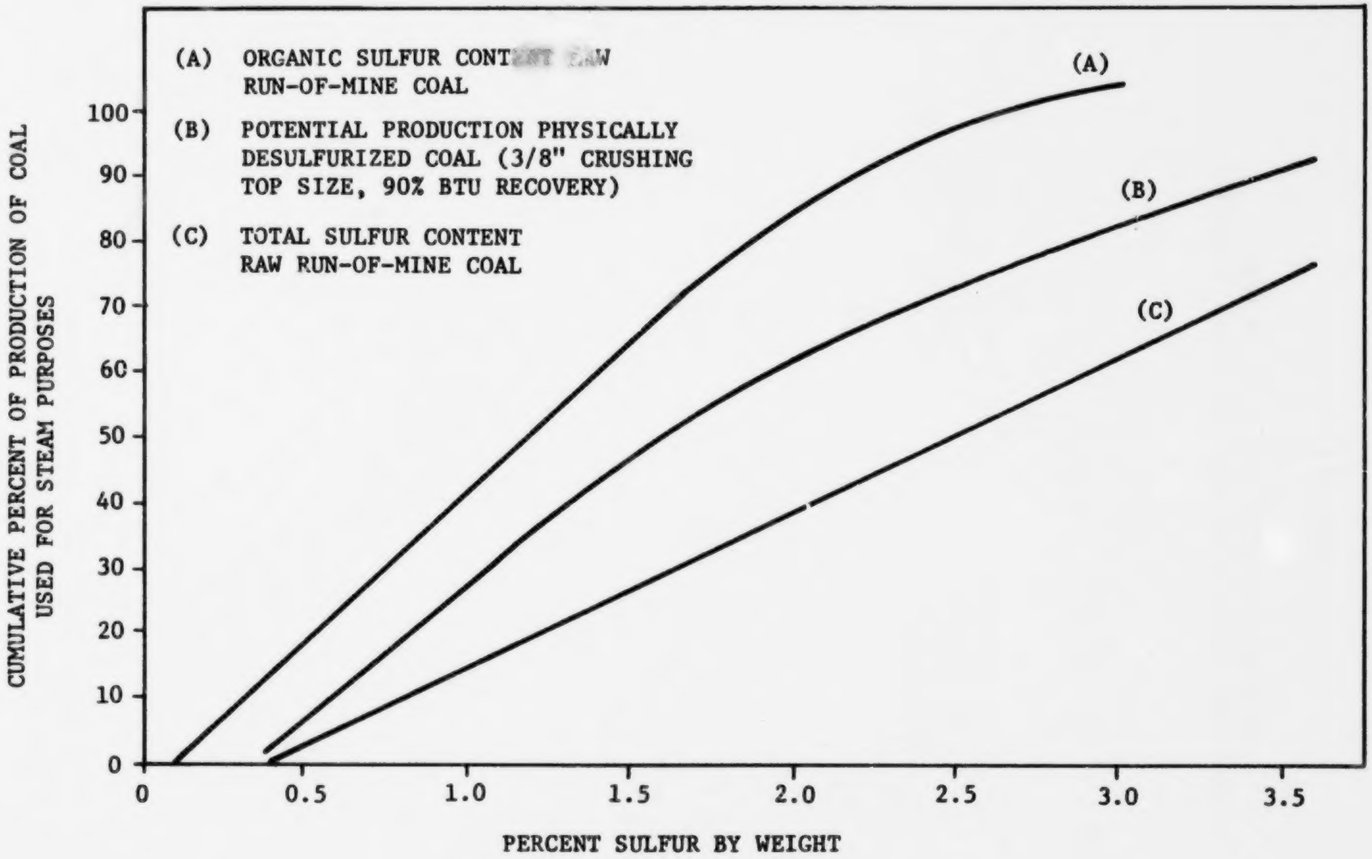

FIGURE 15

ESTIMATED PHYSICAL DESULFURIZATION POTENTIAL OF EASTERN BITUMINOUS STEAM COAL PRODUCTION and benefit factor based on these thirty source/destination case studies.

The difference between the sum of cost factors and benefit factors (Tables LV and LVI) defines the economics of clean coal utilization for specific cases. The thirty case studies examined indicate a net coal desulfurization cost ranging from a $0.44/ton saving to a $2.63/ton cost increase based on an F. O. B. raw coal value of $7.00 per ton. This economic effect translates on a heat content basis into a range from a zero to a 9¢/MBTU cost increase. Figure 16 represents this economic distribution in terms of cost/MBTU for the thirty cases studied.(28)

TABLE LIV

ECONOMIC RANGE OF EACH COST AND BENEFIT FACTOR PER TON OF PHYSICALLY DESULFURIZED COAL

COST FACTORS:	
Amortization contribution	0.37 to 0.57
O & M charge	0.40 to 0.73
Raw coal value lost	0.13 to 3.84
Tax contribution	0.05 to 0.08
TOTAL COST	$0.94 to $5.22
BENEFIT FACTORS:	
Value of additional coal heat content	0.06 to 1.34
Transportation saving	0 to 1.06
Welfare saving	0.01 to 0.08
Ash disposal saving	0.03 to 0.58
Grinding cost saving	0 to 0.05
Plant maintenance saving	0.05 to 0.20
TOTAL BENEFIT	$0.15 to $3.31

TABLE LV

COST FACTORS PER TON CLEANED COAL

$$\text{AMORTIZATION OF CLEANING PLANT} = \frac{\text{YEARLY AMORTIZATION COST PER TON HR. INPUT CAPACITY}}{\text{8760 x UTILIZATION (decimal value) x YIELD (decimal value)}}$$

O & M - BASED ON HISTORICAL DATA, IDENTIFICATION OF COST COMPONENTS. COST ESCALATION FACTORS, AND PLANT YIELD

$$\text{VALUE OF "ADDITIONAL" RAW COAL} = \text{PER TON RAW COAL VALUE} \left(\frac{1}{\text{YIELD (decimal value)}} - 1 \right)$$

$$\text{TAX} = \frac{\text{PLANT COST PER TON HR. INPUT CAPACITY x TAX RATE}}{\text{8760 x UTILIZATION (decimal value) x YIELD (decimal value)}}$$

TABLE LVI

BENEFIT FACTORS PER TON CLEANED COAL

INCREASED HEAT CONTENT = F.O.B. RAW COAL COST PER TON . $\frac{X}{1 + X}$

TRANSPORTATION SAVING = TRANSPORTATION COST PER TON . $\frac{X}{1 + X}$

ASH DISPOSAL COST SAVING = COST TO DISPOSE OF TON OF ASH .$X (1 + X)$

GRINDING COST SAVING = COST TO GRIND A TON OF COAL . $\frac{X}{1 + X}$

BENEFIT COST SAVING = PAYMENT RATE . $\frac{X}{1 + X}$

MAINTENANCE SAVING - BASED ON TVA COLLECTED DATA

X = (DECIMAL INCREASE IN HEAT CONTENT DUE TO CLEANING)

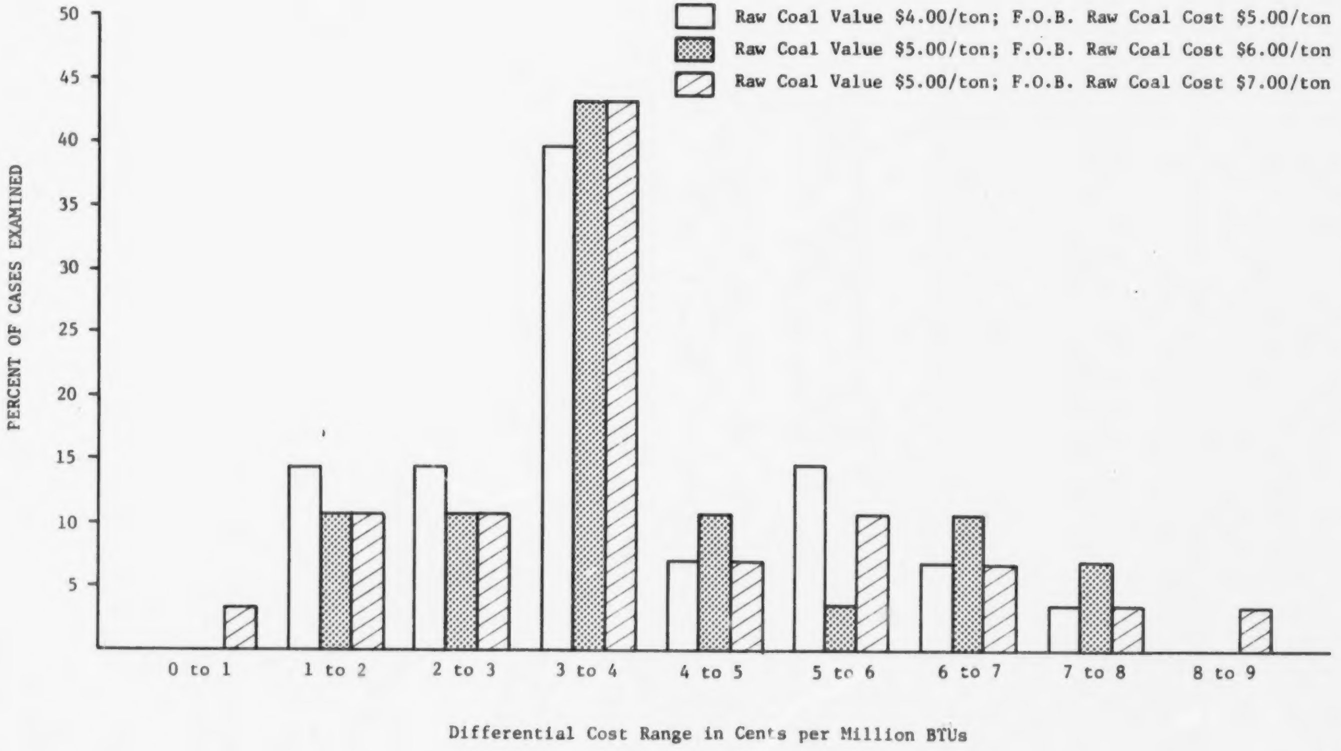

FIGURE 16
DIFFERENTIAL CLEANING COSTS LESS BENEFITS
(UNIT TRAIN SHIPPING RATES)

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APPENDIX I

AMERICAN SOCIETY FOR TESTING MATERIALS STANDARDS CLASSIFICATION OF COAL

TABLE I-1

ASTM CLASSIFICATION BY RANK (D388)[a]

Class	Group	Fixed Carbon Limits, per cent (Dry, Mineral-Matter-Free Basis)		Volatile Matter Limits, per cent (Dry, Mineral-Matter-Free Basis)		Calorific Value Limits, Btu per pound (Moist,[b] Mineral-Matter-Free Basis)		Agglomerating Character
		Equal or Greater Than	Less Than	Greater Than	Equal or Less Than	Equal or Greater Than	Less Than	
I. Anthracitic	1. Meta-anthracite.	98	...	...	2	...	...	Nonagglomerating
	2. Anthracite.	92	98	2	8	...	...	
	3. Semianthracite[c]	86	92	8	14	...	...	
II. Bituminous	1. Low volatile bituminous coal	78	86	14	22	...	...	Commonly agglomerating[e]
	2. Medium volatile bituminous coal	69	78	22	31	...	...	
	3. High volatile A bituminous coal	...	69	31	...	14 000[d]	...	
	4. High volatile B bituminous coal	...	...	...	...	13 000[d]	14 000	
	5. High volatile C bituminous coal	...	...	...	...	11 500	13 000	
						10 500	11 500	Agglomerating
III. Subbituminous	1. Subbituminous A coal . . .	...	...	...	...	10 500	11 500	Nonagglomerating
	2. Subbituminous B coal . . .	...	...	...	...	9 500	10 500	
	3. Subbituminous C coal . . .	...	...	...	...	8 300	9 500	
IV. Lignitic	1. Lignite A	...	...	...	...	6 300	8 300	
	2. Lignite B	...	...	...	...	...	6 300	

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[a] This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48 per cent dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free British thermal units per pound.

[b] Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

[c] If agglomerating, classify in low-volatile group of the bituminous class.

[d] Coals having 69 per cent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.

[e] It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and there are notable exceptions in high volatile C bituminous group.

APPENDIX II

AVERAGE AS RECEIVED HEAT CONTENT OF STEAM COALS

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AVERAGE AS RECEIVED HEAT CONTENT OF STEAM COALS

Estimates were made of the weighted heat contents of "as received" samples of current production steam coals. Due to the limited sampling and possible geographic sampling bias, the numbers may or may not be representative of current production. These weighted average heat contents are given by basin or region. In addition the estimated average BTU content of production steam coal by state is also provided.

For the Northern and Southern Appalachian Basins the provided heat content values are based on weighted BTU values obtained from samples within each producing region according to (estimated) 1970 steam coal production tonnage values.(25) For the Eastern and Western Interior Basins and the West Coast Region the provided values are based on average "as received" BTU values by state and state coal production levels.(15) For the two Rocky Mountain Regions, heat content values are based on BTU information as obtained from our data base and state production levels. Tables II-1 to II-7 provide these steam coal heat content values.

TABLE II-1

AS RECEIVED BTU VALUES FOR STEAM COALS FROM THE NORTHERN APPALACHIAN BASIN

State	Average BTU Value (per pound of coal)
Maryland	13,600
Pennsylvania	13,500
(Northern) West Virginia	13,400

Weighted Average BTU Value - 13,500

TABLE II-2

AS RECEIVED BTU VALUES FOR STEAM COALS FROM THE SOUTHERN APPALACHIAN BASIN

State	Average BTU Value (per pound of coal)
Alabama	13,400
(Eastern) Kentucky	13,400
Tennessee	13,400
Virginia	13,800
(Sourthern) West Virginia	13,700

Weighted Average BTU Value - 13,600

TABLE II-3

AS RECEIVED BTU VALUES FOR STEAM COALS FROM THE EASTERN INTERIOR BASIN

State	Average BTU Value (per pound of coal)
Illinois	11,400
Indiana	11,500
(Western) Kentucky	12,160
Ohio	12,250

Weighted Average BTU Value - 12,000

TABLE II-4

AS RECEIVED BTU VALUES FOR STEAM COALS FROM THE WESTERN INTERIOR BASIN

State	Average BTU Value (per pound of coal)
Iowa	10,000
Kansas	12,500
Missouri	11,400
Oklahoma	13,000
Texas	11,300

Weighted Average BTU Value - 11,750

TABLE II-5

AS RECEIVED BTU VALUES FOR STEAM COALS FROM THE NORTHERN ROCKY MOUNTAIN REGION

1. Bituminous

State	Average BTU Value (per pound of coal)
Montana	10,700
Wyoming	11,700

Weighted Average BTU Value - 11,700

2. Subbituminous

State	
Montana	8,700
Wyoming	9,400

Weighted Average BTU Value - 9,400

TABLE II-6

AS RECEIVED BTU VALUES FOR STEAM COALS FROM THE SOUTHERN ROCKY MOUNTAIN REGION

1. Bituminous

State	Average BTU Value (per pound of coal)
Colorado	12,000
New Mexico	11,750
Utah	12,700

Weighted Average BTU Value - 12,200

2. Subbituminous

State	
Arizona	10,150
Colorado	9,600
New Mexico	10,300
Utah	10,550

Weighted Average BTU Value - 10,100

TABLE II-7

AS RECEIVED BTU VALUES FOR STEAM COALS FROM THE WEST COAST REGION

State	Average BTU Value (per pound of coal)
Oregon	9,100
Washington	10,700

Weighted Average BTU Value - 10,700

APPENDIX III

COMPUTER PROGRAM USED TO ESTIMATE SULFUR DISTRIBUTIONS OF ROCKY MOUNTAIN STRIPPABLE COAL RESERVES

APPENDIX III

COMPUTER PROGRAM USED TO ESTIMATE SULFUR DISTRIBUTIONS OF ROCKY MOUNTAIN STRIPPABLE RESERVES

1.0 INTRODUCTION

In order to estimate the coal reserves in each sulfur category, it was necessary to build a data base of coal analyses. It was assumed that these analyses would be representative of the coal reserves and, therefore, could be used to distribute reserves into the various sulfur categories. The following discussion describes the data base and the computer program that manipulates it. The data base is comprised of over 1900 analyses.

2.0 THE DATA BASE

The Coal Analysis Data Base contains proximate analyses and BTU calorific values for samples taken from the important coal fields of the western states. The majority of the analyses were obtained from the U. S. Bureau of Mines Publication series, "Analyses of Tipple and Delivered Samples of Coal," covering the years 1948 through 1969. Additional sources of information were the U. S. Bureau of Mines publication, "Forms of Sulfur in U. S. Coals," the State of Montana Bureau of Mines and Geology publication, "Montana Coal Analyses," and other publications from various state and federal organizations. A complete list of information sources is given in section 4.0 of this appendix. Presently identified additional sources would allow the data base to be extended. This extension, by providing a greater number of data points, would thereby increase the reliability of the data base statistics.

The data base records the following types of measurements:

- Moisture (percent as received)
- Volatile Matter (percent moisture free)
- Fixed Carbon (percent moisture free)
- Ash (percent moisture free)
- Total Sulfur (percent moisture free)
- Pyritic Sulfur (percent moisture free)
- Organic Sulfur (percent moisture free)
- BTU Calorific Value (as received)
- Number of analyses averaged for the reported measurements
- Grindability Index

Ideally, every analysis would contain a value for each measurement type, but, in practice, the various information sources differ considerably. For example, the publication series, "Analysis of Tipple and Delivered Samples of U. S. Coals," does not contain pyritic or organic sulfur measurements, while the publication, "Forms of Sulfur in U. S. Coals," does not contain values for fixed carbon, volatile matter, or BTU content. The only items consistently present are moisture, ash, and total sulfur.

Each analysis in the data base is identified by location, year, coal type, and information source. The specific identification items which may be recorded are:

- State
- County
- Town or county subdivision (not used at present)
- Coal field or region
- Mine (not used at present)
- Year
- Coal Type
    - Kind of sample:
        - as mined
        - crushed $\geq$ 2"
        - crushed 3/4" to 2"
    - Rank (bituminous, subbituminous, lignite)
- Information source

Here, also, the information sources differ in content, but state and county are consistently present. Identification by coal field or region is accomplished by referring to the coal field maps in the "Keystone Coal Industry Manual," 1970 and to maps furnished by the various state organizations. In many cases, knowledge of the county serves to identify the coal field. Where several coal fields are in the same county, the town or coal mine is located on a map and the appropriate field is assigned to the sample. Major coal fields of the western states are indicated in Figure 10. The smaller fields have been grouped with the nearest major field (for example, the Kemmerer Field in Wyoming is listed as part of the Green River Region) and adjacent small fields have been assigned collective names (for example, the North Central Fields and Southwestern Fields in Montana and the Kaiparowits-Harmony Area in Utah). These assignments were partly for data processing convenience, but in many cases were due to the inability to locate towns or coal mines on the maps.

The year identification refers to the year in which the sample was taken and depending on the information source may be either the fiscal year or the calendar year. In a few cases where the year was not present, the document's publication date was used. Consequently, the year identification is an approximate value to be used for classifying the measurements as being either "old" or "new".

Classification of coal by kind and rank was relatively simple since almost all of the publications give this information. When it was not present, the particular sample was rejected. (Several samples in the important Fort Union Region in Montana were kept, however.) The rank classification, when not given explicitly, was determined from the BTU calorific value on a moist, mineral-free basis. This was computed from the "as received" value according to the following equation.

$$\mathrm{BTU}_{\text{(moist, mineral free)}} = \mathrm{BTU}\ \text{(as received)} * \frac{1}{1-A}$$

where A is the decimal ash content (i.e., $\frac{\%A}{100}$) as received.

The rank classification was then based on the following table.

RANK	$\text{BTU}_{\text{(moist, mineral free)}}$
Bituminous	> 11,500
Subbituminous	> 8,300 and ≤ 11,500
Lignite	≤ 8,300

3.0 THE COMPUTER PROGRAM

A computer program was written to list the data base and to compute basic statistics on the measurement values. The samples may be grouped according to any of the identification items described previously and by sulfur content and BTU calorific value. Each sample group has the following statistics computed for every measurement type:

- Minimum
- Average
- Maximum
- Standard deviation
- Number of samples

3.1 Program Inputs

The basic input to the program is the Coal Analysis Data Base which has already been discussed. Table IV-1 gives the data base format. The other input items are the option cards, the selection cards, and the tables for interpreting the identification codes.

Table IV-2 gives the option card format. The first card determines the method of selecting data base records and whether the selected records will be printed and their summary statistics computed. The second card contains the maximum number of selection groups.

Table IV-3 gives the selection card formats. For each selection group there is one Type 1 card which contains sulfur and BTU limits and up to eight Type 2 cards which contain data base identification codes. A data base record will be selected if it is within the sulfur and BTU limits and if its identification fields match the identification fields of any single selection card. In this latter case, blank identification codes on the selection cards indicate that the field is not to be used for selection purposes.

Table IV-4 gives the card format for the identification tables. Individual tables are separated by a blank card.

TABLE III-1

COAL ANALYSIS DATA BASE FORMAT

CHARACTER NUMBERS	FIELD DEFINITION	TYPE OF FIELD
1-2	State Code	Identification
3-4	County Code	Identification
5-6	Town or County Subdivision Code	Identification
7-8	Coal Field or Region Code	Identification
9-10	Coal Mine Code	Identification
11-12	Year (last 2 digits)	Identification
13-14	Kind of Sample "01" = as mined "02" = crushed $\geq$ 2" "03" = crushed $\bar{3}$/4" to 2"	Identification
15-16	Rank of Sample "01" = bituminous "02" = subbituminous "03" = lignite "04" = anthracite	Identification
17-19	Percent Moisture* (as received)	Analysis Value
20-22	Percent Volatile Matter* (moisture free)	Analysis Value
23-25	Percent Fixed Carbon* (moisture free)	Analysis Value
26-28	Percent Ash* (moisture free)	Analysis Value
29-31	Percent Total Sulfur* (moisture free)	Analysis Value
32-34	Percent Pyritic Sulfur* (moisture free)	Analysis Value

TABLE III-1 (CONTINUED)

COAL ANALYSIS DATA BASE FORMAT

CHARACTER NUMBERS	FIELD DEFINITION	TYPE OF FIELD
35-37	Percent Organic Sulfur* (moisture free)	Analysis Value
38-42	BTU Calorific Value (as received)	Analysis Value
43-45	Number of Analyses Averaged	Analysis Value Supplement
46-47	Grindability Index	Analysis Value
48-75	Unused	
76	Sulfur Decimal Point Indicator blank or "1" = sulfur recorded as 1/10 percent "2" = sulfur recorded as 1/100 percent	Analysis Value Supplement
77-80	Information Source Code	Identification

* Percentages are recorded to the nearest 1/10%. The decimal point is not placed in the data base record, but its location to the left of rightmost digit is implied. Sulfur may be recorded to the nearest 1/100%. (See column 76.)

TABLE III-2

OPTION CARD FORMATS

a. First Option Card

Column Number	Contents	Meaning
1	0	Only those data base records specified on the selection cards will be selected
	1	All data base records will be selected. The second option card and the selection cards will not be read by the program.
2	0	The selected records will be printed.
	1	The selected records will not be printed.
3	0	Summary statistics will be computed.
	1	Summary statistics will not be computed.

b. Second Option Card

Column Number	Contents
1-5	The maximum number of selection groups. The program uses this number to allocate core storage.

TABLE III-3
SELECTION CARD FORMATS

a. Type 1 Selection Card

Character Numbers	Field Definition
1-5	Lowest percent sulfur to be summarized
6-10	Highest percent sulfur to be summarized (if zero, the program will insert 999.99)
11-15	Lowest BTU value to be summarized
16-20	Highest BTU value to be summarized (if zero, the program will insert 999999)

b. Type 2 Selection Card

Character Numbers	Field Definition
1-2	State Code
3-4	County Code
5-6	Town or County Subdivision Code
7-8	Coal Field or Region Code
9-10	Coal Mine Code
11-12	Year (last 2 digits)
13-14	Kind of Sample
15-16	Rank of Sample
17-20	Information Source Code

TABLE III-4

IDENTIFICATION TABLE CARDS

TABLE	COLUMNS	CONTENTS
State	1-2	State Code
	3-18	State Name
County	1-2	State Code
	3-4	County Code
	5-20	County Name
Town		Not used at present
Field or Region	1-2	Field Code
	3-26	Field Name
Mine		Not used at present
Kind	1-2	Kind Code
	3-18	Kind Name
Rank	1-2	Rank Code
	3-18	Rank Name

3.2 Example of Program Outputs

- Table IV-5 is the data base summary statistics for a particular state and region (i.e. Wyoming, Powder River region).
- Table IV-6 provides amplification of the statistics given in Table IV-5 by sulfur content.
- The computer program also has provided a listing of the entire data base which is available as a separate document.

4.0 DATA BASE INFORMATION SOURCES

4.1 From Non-Federal State Agencies and Schools:

- Coal, Oil, Natural Gas, Helium, and Uranium in Arizona (Arizona Bureau of Mines, Bulletin 82)
- Montana Coal Analyses (Montana Bureau of Mines and Geology, Bulletin 78)

4.2 Bureau of Mines Publications:

- Carbonizing Properties of Wyoming Coals (RI 5731)
- Sulfur Contents of United States Coals (IC 8312)
- Analyses of Tipple and Delivered Samples of Coal (1969) (RI 7346)
- Analyses of Tipple and Delivered Samples of Coal (1968) (RI 7219)
- Analyses of Tipple and Delivered Samples of Coal (1967) (RI 7104)
- Analyses of Tipple and Delivered Samples of Coal (1966) (RI 6904)
- Analyses of Tipple and Delivered Samples of Coal (1965) (RI 6792)

TABLE III-5

```
                           DATA SELECTION NO.  1
------------------------------------------------------------------------------------------
STATE
  COUNTY              FIELD                             KIND
    TOWN                MINE                      YEAR    RANK               REF
------------------------------------------------------------------------------------------
WYOMING
  ----------------    POWDER RIVER REGION *             ----------------
    ----------------    ----------------          19--    SUBBITUMINOUS


SULFUR LIMITS :    0.00 999.99
   BTU LIMITS :       0 999999



                           SUMMARY STATISTICS
------------------------------------------------------------------------------------------

           MOISTURE  VOLATILE  FIXED      ASH    TOTAL   PYRITIC  ORGANIC    BTU    NUMBER OF  GRINDABILITY
                      MATTER   CARBON            SULFUR  SULFUR   SULFUR            ANALYSES     INDEX
MINIMUM :    17.9     39.7     43.1       3.9    0.30    0.01     0.31      7190       1          40
AVERAGE :    24.5     43.6     49.9       6.8    0.63    0.10     0.50      9086       2          50
MAXIMUM :    32.8     48.0     54.7      22.0    2.70    0.42     0.82     10070      20          62
STD DEV :     3.51     1.53     2.84      2.82   0.33    0.11     0.14     681.1      2.9         7.8
SAMPLES :    105       89       89       105     105      16       16        89       76          15
```

TABLE III-6

```
                                DATA SELECTION NO.  2
----------------------------------------------------------------------------------------------------
STATE
  COUNTY              FIELD                              KIND
    TOWN                MINE                     YEAR     RANK                  REF
----------------------------------------------------------------------------------------------------
WYOMING
  ----------------    POWDER RIVER REGION *              ----------------
    ----------------    ----------------         19--     SUBBITUMINOUS


SULFUR LIMITS :    0.00   0.49
   BTU LIMITS :       0 999999



                                 SUMMARY STATISTICS
----------------------------------------------------------------------------------------------------

              MOISTURE  VOLATILE   FIXED      ASH     TOTAL    PYRITIC   ORGANIC     BTU   NUMBER OF  GRINDABILITY
                         MATTER    CARBON             SULFUR   SULFUR    SULFUR            ANALYSES      INDEX
MINIMUM :       20.2      41.5      48.0      3.9      0.30     0.01      0.31      8121       1          41

AVERAGE :       25.5      43.4      51.7      5.3      0.40     0.05      0.36      9075       1          51

MAXIMUM :       31.6      46.0      54.7      8.2      0.48     0.08      0.44      9790       1          62

STD DEV :        2.57      1.30      1.70     1.09     0.04     0.03      0.05      410.7     0.0         9.8

SAMPLES :        27        22        22       27       27        5         5         22       16          5
```

TABLE III-6

```
                              DATA SELECTION NO.  3
------------------------------------------------------------------------------------------
STATE
  COUNTY              FIELD                          KIND
    TOWN               MINE                    YEAR   RANK                REF
------------------------------------------------------------------------------------------
WYOMING
  ---------------     POWDER RIVER REGION *          ---------------
    ---------------     ---------------        19--    SUBBITUMINOUS


SULFUR LIMITS :    0.50   0.69
   BTU LIMITS :        0 999999



                              SUMMARY STATISTICS
------------------------------------------------------------------------------------------

             MOISTURE  VOLATILE   FIXED      ASH     TOTAL   PYRITIC  ORGANIC    BTU   NUMBER OF  GRINDABILITY
                        MATTER    CARBON             SULFUR   SULFUR   SULFUR          ANALYSES      INDEX
MINIMUM :      17.9      41.0      44.9      4.0     0.50     0.01     0.42     7790       1          42
AVERAGE :      23.4      43.7      50.1      6.3     0.55     0.06     0.51     9282       2          50
MAXIMUM :      31.0      48.0      53.9     11.1     0.67     0.13     0.57    10070      14          59
STD DEV :       3.13      1.49      2.62     1.66    0.05     0.05     0.06    572.0      2.7         7.4
SAMPLES :      47        40        40       47       47        7        7       40        36           5
```

TABLE III-6 (CONTINUED)

DATA SELECTION NO. 4

STATE COUNTY TOWN	FIELD MINE	YEAR	KIND RANK	REF
WYOMING ---------------- ----------------	 POWDER RIVER REGION * ----------------	 19--	 ---------------- SUBBITUMINOUS	

SULFUR LIMITS : 0.70 0.99
BTU LIMITS : 0 999999

SUMMARY STATISTICS

	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	TOTAL SULFUR	PYRITIC SULFUR	ORGANIC SULFUR	BTU	NUMBER OF ANALYSES	GRINDABILITY INDEX
MINIMUM :	18.4	41.1	43.1	5.3	0.70	0.09	0.60	7450	1	40
AVERAGE :	24.9	44.0	48.7	7.5	0.77	0.10	0.64	8979	2	48
MAXIMUM :	32.8	45.8	53.0	15.6	0.90	0.11	0.68	10020	20	56
STD DEV :	4.54	1.46	2.61	2.62	0.08	0.01	0.06	806.1	4.2	7.9
SAMPLES :	25	23	23	25	25	2	2	23	21	4

TABLE III-6 (CONTINUED)

DATA SELECTION NO. 5

```
--------------------------------------------------------------------------------------------------------
STATE
  COUNTY              FIELD                            KIND
    TOWN                MINE                     YEAR    RANK                REF
--------------------------------------------------------------------------------------------------------
WYOMING
  ----------------    PCWDER RIVER REGION *              ----------------
    --,--------------   ----------------         19--    SUBBITUMINOUS


SULFUR LIMITS :    1.00   1.49
   BTU LIMITS :       C 999999
```

SUMMARY STATISTICS

	MOISTURE	VOLATILE MATTER	FIXED CARBON	ASH	TOTAL SULFUR	PYRITIC SULFUR	ORGANIC SULFUR	BTU	NUMBER OF ANALYSES	GRINDABILITY INDEX
MINIMUM :	24.6	40.0	43.4	9.7	1.00	0.31	0.61	7190	0	0
AVERAGE :	26.7	40.0	43.4	14.0	1.10	0.36	0.71	7190	0	0
MAXIMUM :	29.1	40.0	43.4	22.0	1.28	0.42	0.82	7190	0	0
STD DEV*:	2.26	-1.00	-1.00	6.93	0.16	0.08	0.15	-1.0	0.0	0.0
SAMPLES :	3	1	1	3	3	2	2	1	0	0

* (-1.00 is a flag that indicates a Standard Deviation could not be computed).

TABLE III-6 (CONTINUED)

```
                                 DATA SELECTION NO.  6

-------------------------------------------------------------------------------------------------------
STATE
  COUNTY              FIELD                          KIND
    TOWN                MINE                   YEAR    RANK                  REF
-------------------------------------------------------------------------------------------------------
WYOMING
  ----------------    PCWDER RIVER REGICN *          ----------------
    ----------------    ----------------       19--    SUBBITUMINOUS


SULFUR LIMITS :    1.50   1.99
   BTU LIMITS :       0 999999



                                  SUMMARY STATISTICS

-------------------------------------------------------------------------------------------------------

              MOISTURE  VOLATILE  FIXED       ASH      TOTAL   PYRITIC  ORGANIC     BTU   NUMBER OF  GRINDABILITY
                         MATTER   CARBON               SULFUR  SULFUR   SULFUR            ANALYSES      INDEX
MINIMUM :       28.7      39.7     43.8       16.5      1.80     0.00     0.00     7500       1          0
AVERAGE :       28.7      39.7     43.8       16.5      1.80     0.00     0.00     7500       1          0
MAXIMUM :       28.7      39.7     43.8       16.5      1.80     0.00     0.00     7500       1          0
STD DEV :      -1.00     -1.00    -1.00      -1.00     -1.00     0.00     0.00     -1.0    -1.0        0.0
SAMPLES :         1         1        1          1         1        0        0        1       1          0
```

TABLE III-6 (CONTINUED)

```
                               DATA SELECTION NO.  7

-----------------------------------------------------------------------------------------------
STATE
  COUNTY             FIELD                          KIND
    TOWN               MINE                   YEAR    RANK                 REF
-----------------------------------------------------------------------------------------------
WYOMING
  ---------------    POWDER RIVER REGION *          ---------------
    ---------------    ---------------        19--    SUBBITUMINOUS


SULFUR LIMITS :   2.00   2.49
   BTU LIMITS :      0 999999


                               SUMMARY STATISTICS

-----------------------------------------------------------------------------------------------

           MOISTURE  VOLATILE   FIXED      ASH     TOTAL   PYRITIC  ORGANIC    BTU   NUMBER OF  GRINDABILITY
                      MATTER    CARBON             SULFUR   SULFUR   SULFUR          ANALYSES      INDEX
MINIMUM :    29.4      41.2      45.0      13.8     2.20     0.00     0.00     7580       1           0
AVERAGE :    29.4      41.2      45.0      13.8     2.20     0.00     0.00     7580       1           0
MAXIMUM :    29.4      41.2      45.0      13.8     2.20     0.00     0.00     7580       1           0
STD DEV :   -1.00     -1.00     -1.00     -1.00    -1.00     0.00     0.00     -1.0     -1.0         0.0
SAMPLES :      1         1         1         1        1        0        0        1        1           0
```

TABLE III-6 (CONTINUED)

```
                              DATA SELECTION NO.  8

------------------------------------------------------------------------------------------
STATE
  COUNTY            FIELD                         KIND
    TOWN              MINE                  YEAR   RANK                 REF
------------------------  ----------------------------------------------------------------
WYOMING
  ---------------   POWDER RIVER REGION *          ----------------
    --------------   ---------------         19--    SUBBITUMINOUS


SULFUR LIMITS :    2.50   2.99
   BTU LIMITS :       0 999999


                                  SUMMARY STATISTICS
------------------------------------------------------------------------------------------

            MOISTURE  VOLATILE   FIXED     ASH     TOTAL   PYRITIC  ORGANIC    BTU   NUMBER OF  GRINDABILITY
                       MATTER   CARBON            SULFUR   SULFUR   SULFUR          ANALYSES      INDEX

MINIMUM :     22.0      43.2     44.8     12.0     2.70     0.00     0.00     8890       1          43

AVERAGE :     22.0      43.2     44.8     12.0     2.70     0.00     0.00     8890       1          43

MAXIMUM :     22.0      43.2     44.8     12.0     2.70     0.00     0.00     8890       1          43

STD DEV :    -1.00     -1.00    -1.00    -1.00    -1.00     0.00     0.00     -1.0    -1.0        -1.0

SAMPLES :       1         1        1        1        1        0        0        1       1           1
```

TABLE III-6 (CONTINUED)

```
                                DATA SELECTION NO.  9
------------------------------------------------------------------------------------------------
STATE
  COUNTY              FIELD                       KIND
    TOWN                MINE               YEAR    RANK              REF
------------------------------------------------------------------------------------------------
WYOMING
  ----------------    POWDER RIVER REGION *        ----------------
    ----------------    ----------------   19--    SUBBITUMINOUS


SULFUR LIMITS :   3.00 999.99
   BTU LIMITS :      0 999999


                                SUMMARY STATISTICS
------------------------------------------------------------------------------------------------

            MOISTURE  VOLATILE   FIXED      ASH     TOTAL   PYRITIC  ORGANIC    BTU  NUMBER OF  GRINDABILITY
                       MATTER    CARBON             SULFUR  SULFUR   .SULFUR          ANALYSES     INDEX
MINIMUM :     0.0      0.0       0.0       0.0      0.00     0.00     0.00      0       0           0
AVERAGE :     0.0      0.0       0.0       0.0      0.00     0.00     0.00      0       0           0
MAXIMUM :     0.0      0.0       0.0       0.0      0.00     0.00     0.00      0       0           0
STD DEV :     0.00     0.00      0.00      0.00     0.00     0.00     0.00     0.0     0.0         0.0
SAMPLES :      0        0         0         0        0        0        0       0       0           0
```

- Analyses of Tipple and Delivered Samples of Coal (1964)
  (RI 6622)
- Analyses of Tipple and Delivered Samples of Coal (1963)
  (RI 6461)
- Analyses of Tipple and Delivered Samples of Coal (1962)
  (RI 6300)
- Analyses of Tipple and Delivered Samples of Coal (1961)
  (RI 6086)
- Analyses of Tipple and Delivered Samples of Coal (1960)
  (RI 5792)
- Analyses of Tipple and Delivered Samples of Coal (1959)
  (RI 5615)
- Analyses of Tipple and Delivered Samples of Coal (1958)
  (RI 5489)
- Analyses of Tipple and Delivered Samples of Coal (1957)
  (RI 5401)
- Analyses of Tipple and Delivered Samples of Coal (1956)
  (RI 5332)
- Analyses of Tipple and Delivered Samples of Coal (1955)
  (RI 5270)
- Analyses of Tipple and Delivered Samples of Coal (1954)
  (RI 5221)
- Analyses of Tipple and Delivered Samples of Coal (1953)
  (RI 5085)
- Analyses of Tipple and Delivered Samples of Coal (1951)
  (RI 5085)
- Analyses of Tipple and Delivered Samples of Coal (1948-50)
  (Bulletin 516)

5.0 ADDITIONAL INFORMATION SOURCES

5.1 From Non-Federal State Agencies and Schools

The information sources given in the previous section contained data amenable to inclusion in the data base within the time constraints of the present effort. The data from these sources were relatively easy to characterize with respect to location, sample quality, and coal rank. For the most part the measurement values were on the same basis (i.e., "as received" or "moisture free" depending on the type of measurement, see section 2.0 of this appendix). However, many additional information sources were identified. These sources will require examination in greater detail to screen unsuitable data and will need additional computer processing to convert the data to our standard basis (section 2.0). A preliminary examination revealed that after screening a number of analyses from these sources could be included in the current data base. In particular, the several hundred coal analyses received from Sun Oil Company, as well as the numerous analyses contained in the Bureau of Mines open file report on Montana coal, would be a valuable extension. Therefore, it is recommended that the data base expansion be undertaken using these additional information sources. The potential increase in data base size and improved reliability of the computed statistics would justify this effort.

5.1 From Non-Federal State Agencies and Schools

- A Review of the Coal Industry in the Western U. S. (Colorado School of Mines, Mineral Industries Bulletin, Vol. 2, No. 5)
- Coal Resources of Colorado (Colorado School of Mines, Mineral Industries Bulletin, Vol. 3, No. 5)
- Preliminary Report, Strippable Coal Resources, McCone County, Montana (Montana Bureau of Mines and Geology, Bulletin 69)
- Strippable Coal Deposits on State Land, Powder River County, Montana (Montana Bureau of Mines and Geology, Bulletin 69)
- Stratigraphy and Economic Geology of the Great Falls-Lewistown Coal Field, Central Montana (Montana Bureau of Mines and Geology, Bulletin 56)
- Geology and Coal Resources of the Foster Creek Coal Deposit, Eastern Montana (Montana Bureau of Mines and Geology, Bulletin 73)
- Montana's Place in the Nation's Coal Energy Picture (Montana Bureau of Mines and Geology)
- Mineral and Water Resources of Montana (Montana Bureau of Mines and Mineral Resources, Special Publication 28)
- Preliminary Summary Report of Strippable Low-Sulfur Coals of Southeastern Montana (Montana Bureau of Mines and Geology)
- The Economic Geology of Coal in New Mexico (New Mexico Bureau of Mines and Mineral Resources, Circular 71)
- A portion of a document being prepared by the Utah Geological and Mineralogical Survey describing coal resources of Utah
- Carcass Canyon Coal Area, Kaiparowits Plateau, Garfield and Kane Counties, Utah (Utah Geological and Mineralogical Survey, Special Studies 25)
- Geology and Coal Resources of the Tropic Area, Garfield County, Utah (Utah Geological and Mineralogical Survey, Special Studies 18)

- Review of the Coal Deposits of Eastern Sevier County, Utah (Utah Geological and Mineralogical Survey, Special Studies 15)
- Progress Report on the Coal Resources of Southern Utah-1963 (Utah Geological and Mineralogical Survey, Special Studies 7)

5.2 Bureau of Mines Publications

- Coal Production from the Uinta Region, Colorado and Utah (IC 8497)
- Washability Examination of Colorado Coals (RI 7467)
- Analysis of the Coal Industry in Boulder-Weld Coalfield, Colorado (RI 6726)
- Strippable Coal Reserves of Montana (Preliminary Report 172)
- Strippable Coal Reserves of North Dakota (Preliminary Report 182)
- Coal Resources of Southwestern Utah (IC 8326)
- Strippable Coal Reserves of Wyoming (Preliminary Report 181)
- Transportation Costs of Fossil Fuels (Interim Report, June 1971)
- Unit Train Transportation of Coal (IC 8444)
- United States Coal Resources and Production (Preliminary Report, June 1971)
- Analysis of the Northern Great Plains Province Lignites and Their Ash: A Study of Variability (RI 7158)

5.3 United States Geological Survey Publications

- Coal Resources of New Mexico (Circular 89)
- Stripping - Coal Resources of the United States - January 1, 1970 (Bulletin 1322)
- Geology of the Crazy Woman Creek Area, Johnson County, Wyoming (Bulletin 1027B)

5.4 Publications from Miscellaneous Sources

- Coal Pipelines - A Reappraisal (American Society of Mechanical Engineers)
- Office of Coal Research/Annual Report 1970
- Office of Coal Research/Annual Report 1971
- Properties of Chars Produced from Low Rank Coals of the Rocky Mountain Region (Fuel, Vol. 41, 1962)
- The Potential Market for Far Western Coal and Lignite [Nathan (Robert R.) Associates, Inc.]